WASTE AND ENERGY AUDIT IN A PAPER MILL

by

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ABSTRACT

Teppattana Paper Mill, a small non-integrated paper mill which manufactures paper and board was selected as the study object in this research study. The study mainly focused to trap potential waste minimization options in the mill. It mainly targeted towards raw water conservation, process modifications, improvement to the effluent treatment plant, energy conservation and to find possibilities for zero discharge.

The study indicated that the raw water consumption is 90 m^3/ton of paper which is 7 times higher than the standard norms and dissolved solids in raw water is 4 times higher than the accepted values. The suspended solid component leaving the manufacturing process is 59 kg/ton of paper. The overall steam energy and electrical energy consumption of the mill is found to be 2 tons/ton of paper and 631 kWh/ton of paper respectively.

Approximately 25% reduction in raw water consumption of the mill and 42% reduction in suspended solids to the primary clarifier is envisaged upon implementaion of waste reduction measures such as water reuse and wastewater segregation.

The study concludes with the proposals to reduce the wastewater discharge to the river by almost 100% and to reduce ground water extraction by 83%.

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LIST OF ABBREVIATIONS

AIT	Asian Institute of Technology
Av.	Average
BOD	Biological Oxygen Demand
B/W	Back Water
^0C	Degree centigrade
CAF	Cavity Air Floatation
C/C	Centricleaner Reject
cm	Centimeter
cm^2	Square centimeter
COD	Chemical Oxygen Demand
C/P	Centricleaned Pulp
CPO	Computer Paper
DS	Dissolved Solids
D/W	Dewatered Pulp
ETP	Effluent Treatment Plant
F	Filtered COD
g	Gram
GAC	Granular Activated Carbon
g/m^2	Grammage
GI	Glass Interleaving Paper
GW	Ground Water
GJ/ton	Giga Joules per ton
h	Hour
HRT	Hydraulic Retention Time
Ht.	Height
kg	Kilogram
kPa	Kilo Pascal
kW	Kilowatt
kWh	Kilowatt hour
L/sec	Liters per second
m^2	Square meter
m^3	Cubic meter
m^3/day	Cubic meters per day
mg	Milligram
mg/L	Milligram per Liter
m/min	Meters minute
min.	Minute
mm	Millimeter
P & W	Printing and Writing Paper
PM	Paper Machine Section
PM I	Paper Machine I
PM II	Paper Machine II
PM III	Paper Machine III

PVA	Poly Vinyl Alcohol
Qty.	Quantity
R/W	Raw Water
SDB	Sludge Drying Beds
SP	Stock Preparation
SP I	Stock Preparation I
SP II	Stock Preparation II
SP III	Stock Preparation III
S/P	Screened Pulp
SS	Suspended Solids
S/R	Screen Reject
SW	Solid Waste
Temp.	Temperature
tonne	Metric tonne
TS	Total Solids
TSS	Total Suspended Solids
U	Utility Section
UNEP	United Nations Environment Program
VP	Virgin Pulp
Vol.	Volume
W/M	Wire Mesh
WP	Waste Paper
WW	Wastewater
$	US Dollars

Comment:

CHAPTER I

INTRODUCTION

1.1 General Background

The paper industry is known to be an intensive industry in every sense of the word: it is raw material intensive, capital intensive, energy intensive, water intensive and also pollution intensive. Therefore, now more than ever before, there is a compelling urgency to control the pollution caused by the paper industry.

The basic paper making process has not changed for the last 2000 years. That process involved soaking the fibers in water, draining on a fine wire screen and then drying under pressure and heat. A modern paper or board mill, however, converts cellulose pulp in a continuous process which uses a number of rollers through which the web of steadily more stable paper is drawn on to a succession of reels.

Although the manufacturing technology has been developed, the pollution emissions to the environment (water, air and land) from the industry have mostly been neglected. Emissions to water and air have to be treated prior to discharge, in order to comply with accepted standards, but there is no quantitative control on the emissions of solid/sludge wastes on land (WEBB, 1994 b).

Presently studies are being conducted on how to achieve zero emissions from the paper industry. However, the Director General of the European chemical industry council believes that objectives such as zero emissions or zero concentrations are not scientifically possible (BURKE, 1995).

1.2 Problem Identification

Until relatively recently, the waste management was concentrated on end-of-pipe treatment, such as primary clarification; biological treatment such as, aerated stabilization basins, oxidation ponds or activated sludge systems; and physical/chemical treatment such as filtration and chemically assisted clarification.

In the early 1970s, people started thinking of developing closed loop technologies that prevent pollution within the manufacturing process. They focused on greater recycling of chemicals and process water within the mill. With the implementation of this new technology, the industry has been steadily reducing water consumption, a trend which reflects the commitment to sustainable development. Reduction of energy is an important benefit of the close up mill water system (WEBB, 1982). However, as WEBB (1985) has pointed out, the closed loop technology will cause problems such as an increase in the concentration of most chemicals, a rise in process temperature and a change in specification of dissolved organics. The latest trend is to adopt cleaner production technologies. This is a creative way of thinking about the products and the process which make them.

It is achieved by continuous application of strategies to minimize the generation of wastes and emissions within the system (CHANDAK et al., 1995).

Most of the external effluent treatment and advanced mill internal pollution control methods developed in industrialized countries need not be adopted in developing countries. There are various reasons for this, such as, lack of expert knowledge, skilled labor and less financial resources to buy advanced and more sophisticated equipment. Even though these problems can be solved, most of the paper mills in developing countries are small and medium scale ones, and often too small to implement most of the latest processes. Therefore a considerable amount of research has to be carried out in order to understand how waste management technologies can be adopted to small mills in developing countries in an efficient manner.

1.3 Objectives

The main objective of this study is to conduct a waste audit in a paper mill. The specific objectives are:

a) To carry out a material balance for each of the unit production processes;
b) To determine the possibilities for closing the water cycles in order to reduce the discharges and emissions;
c) To determine the possibilities of recovery and re-use of fibre from the waste streams;
d) To propose to the management some important cleaner production technologies;
e) To propose to the management how to improve its energy management strategies;
f) To prepare a general plan to achieve possible zero liquid discharge.

1.4 Scope and Limitations

This study was carried out in the Teppattana Paper Mill Co. Ltd., Pathumthani, which manufactures paper and board. The main focus of this research study is to find out how to reduce the prevailing ground water extraction of 2900 m^3/day while keeping the production at the same quantity.

The study will basically involve material balance, particularly the fibre and water balance. Consistency balance is another important parameter. However, this is difficult to measure in the absence of costly instrumentation. The data for the energy balance is obtained as far as possible from the available data in the factory.

The results of this study will specifically be beneficial to Teppattana Paper Mill Co. Ltd., in Pathumthani. However, findings of this research will be helpful as a guide to other paper mills wanting to adopt cleaner production technologies.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction to Paper Industry

World wide more than 268.6 million tonnes of paper and board were produced in the year 1994. This includes 33.8 million tonnes of news print, 79 million tonnes of printing and writing paper, 102 million tonnes of packaging paper and board and 53.8 million tonnes of other paper and board. Thailand, for instance, in 1994 had a production output of 1.7 million tonnes of paper and board (BRENNAN and PAPPENS, 1995) from 45 paper and board manufacturing mills (ANONYMOUS II, 1995). MYREEN (1994) predicts that the world production of paper and board will exceed 310 million tonnes in the year 2000.

As with virtually every individual process, manufacture of paper and board uses large quantities of resources, and causes environmental pollution due to high energy and water consumption, destruction of forests, and emissions of liquid, solid and gases to the receiving environment.

2.2 Types of Products

The paper could be classified into six types namely (ANONYMOUS I, 1991) :

- News Print
- Printing and Writing Paper
- Case Making Materials
- Packaging Papers and Boards
- Household and Toilet Tissue
- Industrial and Special Purpose Papers

Depending on the type of paper produced, raw material consumption, water consumption, energy consumption and the solid loss will vary.

2.3 Raw Materials

Raw material for paper industry is classified as follows (ENERGY MANAGEMENT CENTER, 1995 and RAYTHEON ENGINEERS and CONSULTANTS INC., 1995):

- Forest-based eg. bamboo and hardwood
- Waste paper based
- Unconventional raw materials based eg. agro-residues, jute, grassed straw, bagasse etc.

In addition to these additives such as fillers, sizing chemicals and dyes are added depending on the requirement of the final product.

2.4 Paper Making Process

In the paper mill, the pulp is converted to paper. An integrated paper mill is situated near a pulp mill and receives the pulp in dried and bladed form whereas in a non integrated mill pulp is purchased from outside. The paper production process in an non-integrated mill can mainly be divided into four stages, namely:

- Stock Preparation
- Paper Machine System
- Finishing and Converting
- Utility Section

2.4.1 Stock Preparation

Stock preparation is the term used to cover those paper making operations involving:

- Repulping and blending of different pulps
- Additions of various chemicals and fillers
- Mechanical treatment to make fibres form into a sheet of paper

Support functions include consistency regulation, proportioning, beating, refining, machine chest mixing and screening.

A typical continuous stock preparation system is shown in Fig. 2.1. The proper portions of various pulps forming the furnish are first added into a hydra pulper. Depending on the requirement, dyes, size, fillers, alum etc. are also added and mixed thoroughly at this point. The furnish is then pumped to a machine chest where the consistency is carefully controlled through the use of automatic consistency regulators. The stock is then fed to the paper machine head box where the furnish (or pulp mixture) is evenly distributed onto the wire screen mesh. The water collected from the wire mesh is continuously recycled to dilute the pulp fed into the paper machine.

2.4.1.1 Screening and Cleaning

The objective of pulp cleaning and screening is to remove dirt and foreign matter such as slivers, grit, bark, sand, stones, metal pieces, plastic, clips etc. The operating principal of screening depends on the size whereas the clean is based on difference in specific gravity. In modern waste paper based stock preparation, the screen receives the stock at around 4% consistency (SIEWERT, 1995) whereas KLINE (1991) and NATIONAL PRODUCTIVITY COUNCIL (1996) says that this consistency should be less than 1%.

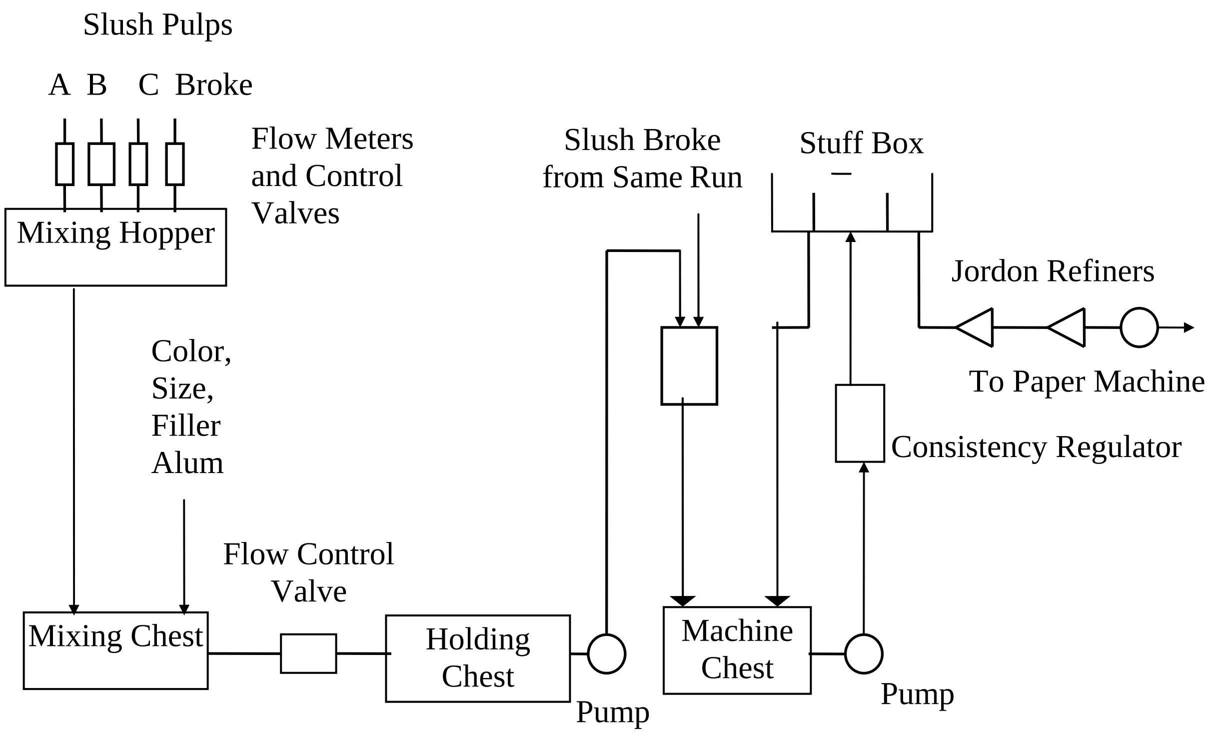

Fig. 2.1 Stock Preparation Process (McCUBBIN, 1983)

Coarse Screen

This is to remove oversize material such as knots, slivers and ungrounded pieces of wood. The screens usually have openings of 5-10 mm in size and may be vibratory, mechanical, open rotary, and centrifugal rotary (McCUBBIN, 1983).

Fine Screen

Fine screen is to remove fibre bundles and particles that are 4 to 20 times larger than average (McCUBBIN, 1983). The size of the opening will normally vary from 2 to 2.5 mm (KLINE, 1991). In early stages open screens were applied. They are vibrating screens and open centrifugal screens. In modern mills closed screen technology is used. This operates under pressure with no free liquid surface.

Cleaning

Centrifugal cleaning is the most common device used in pulp cleaning to remove bark, sand, grit and other small particles. Here dilute pulp (<1% consistency) is fed tangentially in a conical separator body causing rapid spinning of the pulp and a downward movement in the cone. Small surface area particles and high specific gravity particles will move downward and lighter and clean fibres carried upward to the accepted discharge (McCUBBIN, 1983 and KLINE, 1991).

2.4.1.2 Stock Refining

This is a mechanical process which acts on fibres to give them increased surface area, greater flexibility and smooth surfaces. The consistency norm for the refiner is in the range of 4% to 4.5%. The specific consumption of energy for different types of refiners are given in Table 2.1. (ENERGY MANAGEMENT CENTER, 1995). KLINE (1991) says that the consistency norm for conical refiners is in the range of 2-10% whereas for double disc refiners it can go upto 30%.

Table 2.1 Comparative Power Consumption of Different Refiners Used (ENERGY MANAGEMENT CENTER, 1995)

Type of Refiner	Specific Energy Consumption (kWh/tonne of pulp)
Conical	9-13
Double disc	7-9
Triple disc	6
Beaters (slushing and refining)	14-18
Hydra pulper (mainly slushing)	11-14

The refiner filling materials are made of steel. In recent developments ceramic filling materials have been invented to reduce the specific energy consumption by 15-20% (SIEWERT, 1995).

2.4.1.3 Thickening

After screening and or cleaning the pulp is usually thickened or dewatered from about 0.5% consistency to 3 to 14% depending on the usage and storage requirement. The thickening is done by either gravity deckers (4 to 8% consistency) or vacuum filters (10 to 20% consistency) (McCUBBIN, 1983).

In newly built paper mills a counter washing principle is adopted. Here the pulp is thickened to a consistency of 30% before transferring to the paper mill (MYREEN, 1994).

2.4.2 Paper Machine System

The paper machine is the mechanical system used to convert the pulp into paper. All paper machines consist of a wet end or forming section, a press section and dryer section (NATIONAL PRODUCTIVITY COUNCIL, 1996).

2.4.2.1 Forming Section

The most common wet end machines in use are:

- Fourdriner
- Twin Wire Former
- Cylinder Machine

Fourdriner

The pulp suspension enters the head box at around 0.5% consistency and flows through the slice opening on to the traveling Fourdriner screen. The operating speed of Fourdriner machines typically varies from 10 to 50 m/min (McCUBBIN, 1983). KLINE (1991) says this speed is normally around 120 m/min and will vary according to the grammage of paper.

Twin Wire Paper Machine

Here the stock is directed through nozzles over the full width of the machine between two Fourdriner type wires. SCACHINGG et al. (1991) described the basic design for twin wire press process for sheet drying applications. This paper says that the energy required for twin wire paper machine is 85% less than that with Fourdriner machines. However it is not used since the yield is less.

Cylinder Machines

Cylinder machines are used primarily for the production of heavy grades of paper or board and may use one or multiple cylinders to form the web depending on the product. The machine operates at 40 m/min on average (McCUBBIN, 1983). Here also the consistency of the stock arriving at the paper machine is around 0.5% (KLINE, 1991).

2.4.2.2 Press Section

After the forming section followed by suction boxes, sheet is transferred from a wire to pickup felt or first press felt by suction pickup roll and enters to the press section where additional moisture removal is achieved. The web attains a consistency of between 30 to 45% before leaving the press section (McCUBBIN, 1983). According to GRANT (1994) a newly invented press called shoe press is expected to achieve a solid content of 48 - 50% after press section. KLINE (1991) says that sheet leaves the forming section at 12 - 16% consistency and it leaves the press section around 25% consistency. It also says that the maximum consistency it can get after press section will vary from 36 - 40%.

2.4.2.3 Dryer Section

The dryer section normally consist of series of steam drying rollers into which paper is led by a dryer fabric. The drying section of the machines are enclosed with machine hoods and vents for removal of moisture-laden air as the drying take place.

The size press is done after the main dryer section. The web is usually quite dry between 4 to 12% moisture content before entering the size press (McCUBBIN, 1983). KLINE (1991) express that the sheet entering the dryer section at around 36-40% consistency and it leaves this section at 95% consistency.

The dried web enters a calender stack where it is compressed and given a smooth surface prior to reeling.

2.4.3 Finishing and Converting

Finishing operations refer to those performed in the finishing room where the paper is prepared for shipment.

Finishing operation can produce about 10% of the total production as dry broke which is repulped and recycled at the stock preparation department (McCUBBIN, 1983).

2.4.4 Utility Section

The utility section comprises water supply, boiler house and electric power supply. The steam requirement is met by boilers. Normally, the make up water requirement for the boiler is met by the softener plant (CHANDAK et al., 1995 and NATIONAL PRODUCTIVITY COUNCIL, 1996).

2.5 Sources of Pollution and its Characteristics

2.5.1 Stock Preparation

Cleaner and screen rejects can be upto few percent of total production, normally under 1% (McCUBBIN, 1983). It is not possible to define an acceptable rate of suspended solids discharge since it depends on product specification and cleanliness of raw materials. The BOD of discharge is generally negligible unless there are significant starch leaks or other losses due to equipment weaknesses. There is no significant atmospheric emission or solid waste from stock preparation department.

2.5.2 Paper Machine System

Stocks generally arrive at the paper machine area at a consistency of between 3 to 12% consistency. The final product is about 90% dry, so that from about 7 to 30 tonnes of water must be discharged per tonne of paper produced. In addition, upto 15 tonnes of water per tonne of paper is added by paper machine showers and agitator seal water, which must be discharged at the same point (McCUBBIN, 1983). RAYTHEON ENGINEERS and CONSULTANTS INC. (1995) says that the typical water consumption for a secondary fibre mill is 12 m^3/tonne of paper produced. MYREEN (1994) confirms it by indicating the fresh water consumption in a paper and board mill varies between 2 to 20 m^3 per tonne of paper produced depending on the grade required. It also indicates that water discharged in cubic meters per tonne of paper produced as follows:

- News Print : 5-15
- Light weight paper : 12-20

- Wood free printing paper : 5-10

METCALF and EDDY (1991) says that fresh water consumption value vary between 120 - 158 m^3/tonne of paper produced. This may be a general value since it does not give the specifications such as the type of raw material, type of process etc.

About 1.5 tonnes of water per tonne of paper is evaporated and a large portion of remaining water is used for stock dilution prior to the paper machine area (McCUBBIN, 1983). But KLINE (1991) says about 2 tonnes of water per tonne of water is evaporated.

2.5.3 Finishing and Converting

Most of the finishing operations produce little or no liquid waste, except in the case of coating operations. This can generate 10% of total production as dry broke which is repulped and recycled at the stock preparation department (McCUBBIN, 1983).

2.5.4 Utility Section

Practically all paper mills have boilers which use bunker carbon oil as fuel. When oil is burned, particulate matter and sulfur compounds are formed. The amount of sulfur compounds depends on the amount of sulfur in the oil (TUPAS, 1995). Mills that use saw dust as fuel will emit unburned carbon particles to the atmosphere when there is no complete combustion.

2.5.5 Effluent Discharge Standards in Paper Industry

There are some countries that have national environmental standards for pulp and paper industry. Apart from national standards, there are four international agreements namely Baltic Sea, North Sea, Nordic Council of Ministers and World Bank (UNEP, 1995).

World Bank effluent guide lines for the non integrated paper mills are presented in Table 2.2.

For most mills suspended solids concentration is under 150 mg/L and the mass flow of suspended solids is 3 kg/tonne of paper, perhaps almost zero. The BOD discharged from the paper machine is around 10 kg/tonne of paper produced (McCUBBIN, 1983).

Characteristic of effluent from medium and small paper mills are given in Table 2.3.

WEBB (1994a) says that most consistent sludge is from non integrated mills as paper making introduced additional sludge generation from non fibrous raw materials. It also says that according to German figures sludge generation is about 65 kg per tonne of paper produced. Gross heating value of dry sludge varies with the ash content from about 10 to 20 GJ/tonne. FOLKE (1994) expresses that the yield of recycled paper may vary from 60% to 95% depending on the pulping technology used, quality of recovered paper and the characteristics required for the products. This means that 53 kg - 667 kg per tonne of product is lost in the production process.

Table 2.2 Effluent Guideline Characteristics for Non Integrated Paper Mills (UNEP, 1995).

Category	BOD kg/tonne of product	TSS kg/tonne of product
Fine paper	4.2	4.2
Tissue paper	4.7	4.7
Tissue paper (from waste paper)	4.7	4.7
De-inking mills	7.0	12.6

Table 2.3 Effluent Characteristics for Small Paper Mills

Parameters	Waste Paper and Purchased Pulp (GOYAL, 1994)	Waste Paper (ENERGY MANAGEMENT CENTER, 1995).
Volume (m^3/tonne)	107	70 -150
pH	7 -7.7	6 - 8.5
SS	542 mg/L	50 - 80 kg/tonne of paper
BOD	542 mg/L	10 - 40 kg/tonne of paper
COD	654 mg/L	50 - 90 kg/tonne of paper

CHANDAK et al. (1995) indicates that generally 20 m^3 wastewater is produced per tonne of paper. WEBB (1985) says that in waste paper based closed mill systems, wastewater temperature can reach 50^0C and COD values of 2000-4000 mg/L.

2.6 Environmental Problems from Paper Industry

The paper making process requires large quantities of water. The fresh water added to the process gives rise to a corresponding amount of excess water contaminated with dissolved and suspended substances.

Noise from the process equipment and from internal and external means of transport is a factor of all mills or factories (UNEP, 1981).

FOLKE (1994) explain that the environmental balance could be affected by recovery of waste paper as raw material for paper products. He continues that when high grade toilet or writing papers are being manufactured from recovered paper, the net effect would be the increase of total solid waste burden, and eliminate the energy value of the recovered paper. The net increase in solid waste burden is due to the fact that the sludge discharged has low or negative calorific value.

The Canadian pulp and paper industry laid down three simple parameters that will cause environmental problems. They are :

a) Suspended Solids, that will smother the breeding grounds of fish;

b) BOD, that will stimulate bacterial activity and deplete the waters oxygen demand;
c) Lethal substances, that will kill 50% or more of the rainbow trout exposed to them during a 96 hour period (DALEY, 1994).

Further, due to degradation and destruction of forests, soil and water which are habitants for fauna, flora and marine species, there is a corresponding reduction of biological diversity (KOLB, 1991).

2.7 Wastewater Treatment Processes

The end of pipe treatment methods used are to neutralize wastewater and reduce the effluent content of SS, BOD or COD, color, toxicity and nutrients.

2.7.1 Pretreatment

Generally wastewater should undergo some kind of pretreatment to overcome the problems of coarse material and acid or alkaline effluent. General methods adopted are screens, grit chamber and neutralization (KLINE, 1991 and UNEP, 1981).

2.7.2 Primary Treatment

Suspended solids which escape from the plant must be removed before discharging the effluent to the receiving waters. The most commonly used methods are gravity settling tanks or flotation clarifier (KLINE, 1991 and UNEP, 1981).

Sometimes chemical flocculation is important in order to remove suspended solids and colloidal solids, some soluble substances and phosphorous. Coagulants such as alum, ferric chloride, lime and poly electrolytes are the commonly used chemicals.

2.7.3 Secondary Treatment

The main objective of secondary treatment is to remove the soluble compounds in wastewater. Biological treatment is the most common treatment method since most of the dissolved organic compounds are biodegradable. Some of the common biological treatment methods are oxidation ponds, facultative ponds, aerated lagoons and trickling filters. A comparison of some secondary treatment methods is shown in Table 2.4.

Table 2.4 Comparison of Secondary Treatment Methods for Paper Mill Effluent

(UNEP, 1981)

Parameters	Stabilization Ponds	Aerated lagoons	Trickling Filters	Chemical flocculation

Area requirement	very large	small	small	small
BOD Loading range (kg/m^3)	0.005-0.01	2-5	1-4	high
BOD reduction %	50-80	40-75	70-95	20-40
Equalization requirement	none	small	large	none
Equalization capacity	very large	small	small	small
Shock resistance	very high	high	limited	high

WEBB (1985) says that the nutrient content present in waste paper based mills is less than the amount required for aerobic treatment and concludes that anaerobic treatment is likely to be cheaper to install and operate than aerobic plants, giving pay back period of 2-3 years in most favorable cases.

2.8 Energy Utilization in Paper Industry

Paper industry is an energy intensive industry. RAGAN (1990) points out that in India, energy costs for an integrated mill contribute to 16-40% of the production cost of paper. The energy requirement is mainly for heat used in steam generation/process heating and as mechanical power to run the plant's electrical motors. Basically energy consumption can be illustrated as in Fig. 2.2.

Steam requirement is met by boilers of capacities ranging from 5 to 10 tonnes of steam per hour. The maximum steam pressure rating is 10 kg/cm^2. The process steam consumption is 2 tonnes per tonne of paper produced at a pressure of 4 kg/cm^2 in the paper machine (CHANDAK et al. 1995 and NATIONAL PRODUCTIVITY COUNCIL, 1996). This is confirmed by ENERGY MANAGEMENT CENTER (1995) where it is stated that the figure varies form 1.9-2.0 tonnes per tonne of paper. However RAGAN (1990) indicates that the steam requirement is 3.64 tonnes per tonne of paper produced.

Specific electrical energy consumption for stock preparation and paper machine is given as 238 kWh and 518 kWh per tonne of paper respectively (AHUJA and BIHANI, 1990) and ENERGY MANAGEMENT CENTER (1995) says that in developing countries, for stock preparation, it is 164-175 kWh/tonne, paper machine 410-415 kWh/tonne and utilities and for others 160-165 kWh/tonne.

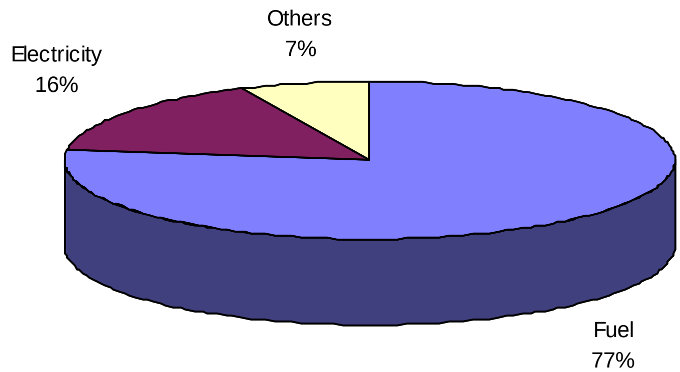

Fig. 2.2 Energy Consumption Pattern in a Paper Mill

For the industry to retain its competitiveness, it is essential to take steps to reduce energy consumption. HABIN (1992) introduced recovery of heat from the condensate of paper machine by using heat exchanger. Here air supplied to the boiler is heated in the heat exchanger. The author concluded that if the boiler efficiency can be increased from 71.2 to 74.6%, coal consumption can be reduced by 10%. The pay back period of the investment is 10 months.

LINANANDA (1986) investigated energy efficient improvement options for heat pump co-generation system for a paper mill in Thailand. He found that the pay back period of insulation for 150 mm and 200 mm lines are 1.34 and 1.24 years respectively.

2.9 Cleaner Production in the Paper Industry

Paper industry is raw material intensive, energy intensive, water intensive and pollution intensive. To solve the existing environmental problems and prepare for challenges resulting from future expansions and tighter pollution regulations, improvement in environmental management technologies and techniques are required.

Cleaner production is a new creative way of approach to achieve the objective of making production less waste intensive. This is achieved by strategies to minimize generation of waste emissions (CHANDAK et al., 1995). The strategy of cleaner production is explained in Fig. 2.3 (RADKA, 1995).

The six steps for cleaner production assessment program are (NATIONAL PRODUCTIVITY COUNCIL, 1996) :

1. Getting Started

2. Analyzing Process Steps
3. Generating Cleaner Production Options
4. Selecting Cleaner Production Solutions
5. Implementing Cleaner Production Solutions
6. Sustaining Cleaner Production

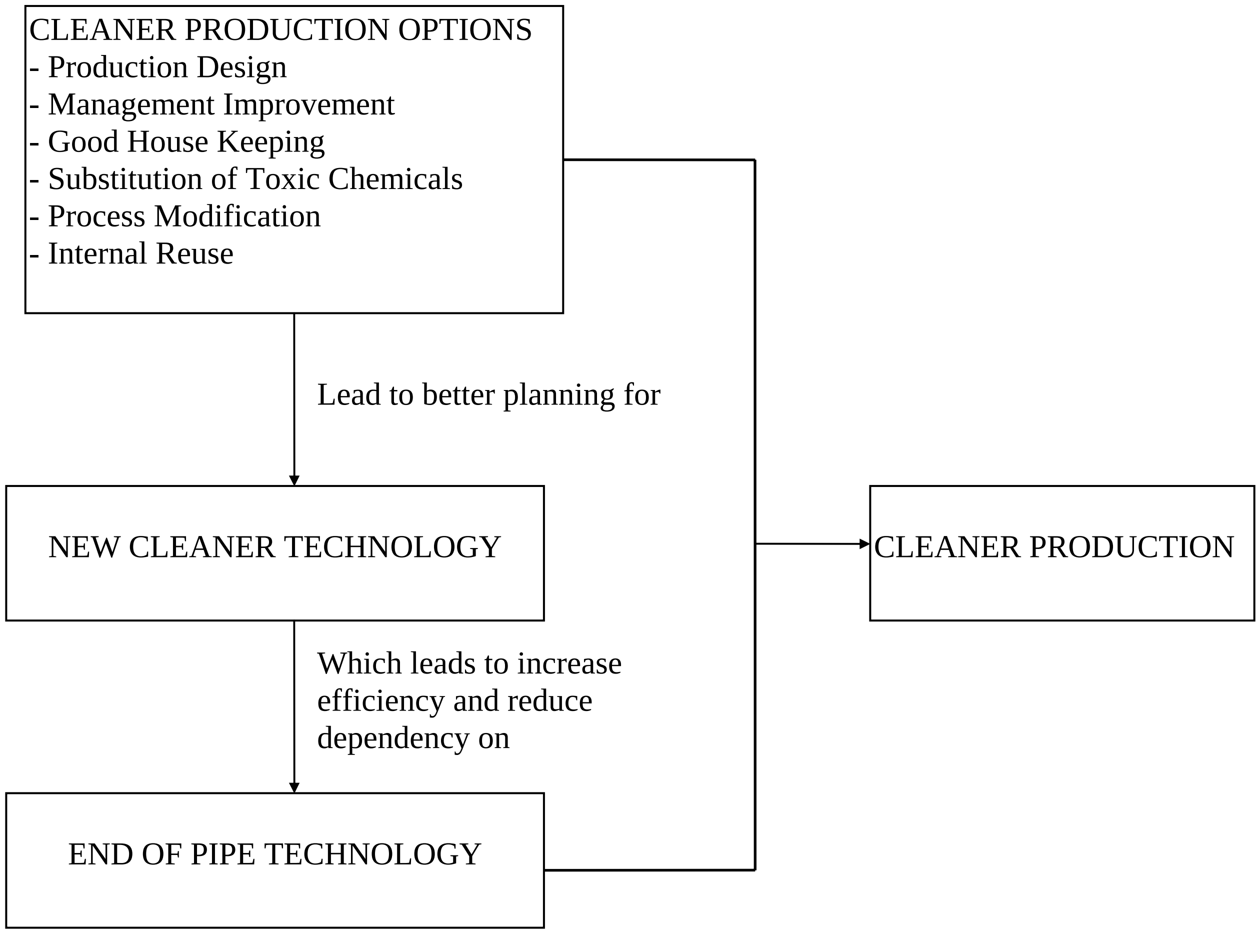

Fig. 2.3 Strategy for Cleaner Production Development (RADKA, 1995)

In a nut shell, philosophy of cleaner production must be developed within the mill concerned. This implies that cleaner production should become an integral part of the companies activities.

CHAPTER III

BACKGROUND INFORMATION OF THE RESEARCH SITE

3.1 General Information

Teppattana Paper Mill Co., Ltd. is a small paper mill located at 220/1, Saiwatkoke Road, Amphur Muang, Pathumthani. The location map of the mill is shown in Fig. 3.1. The layout of the mill is presented in Fig. 3.2.

The paper mill was established in 1970 with a registered capital of 5.2 million Dollars. The total number of employees are 224.

The factory has three production lines namely PM I, PM II and PM III to manufacture three products namely duplex board, printing and writing paper and glass interleaving paper respectively with daily manufacturing capacities of 30 tonnes, 14 tonnes and 6 tonnes respectively. The actual manufacturing quantity will depend on the demand for each product. During high demand periods for glass interleaving paper, the PM II is designed to convert for glass interleaving paper with some modifications. The total production is consumed in Thailand and discussions are in the progress to export printing and writing paper to India.

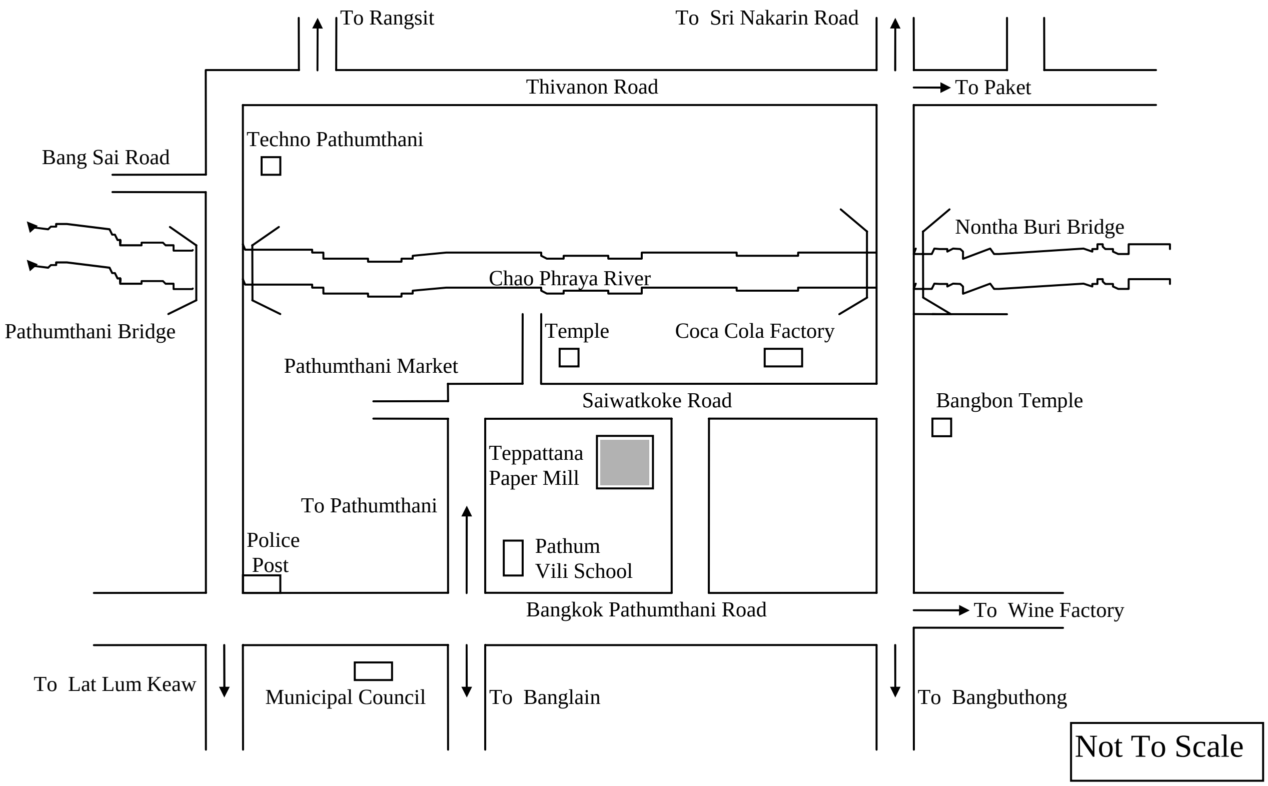

Fig. 3.1 Location Map of Teppattana Paper Mill

3.2 Production Process

The raw material used for different products are described below.

Duplex Board : A mixture of 43% waste magazines, 43% card board boxes and 14% white paper are added separately to the hydra pulper. These are not mixed in the stock preparation process but conveyed separately to the wet end of the paper machine. No de-inking of waste paper is done in this operation. The average grammage of paper is found to be 310 g/m^2 on average.

Printing and Writing Paper : A mixture of white paper 60% and virgin pulp 40% are added to the hydra pulper and mixed in a chest. The grammage of paper is found to be 70 g/m^2.

Glass Interleaving Paper : This is produced by using the cutting edges of news papers. Here the grammage of paper is found to be 35 g/m^2.

Chemicals such as alum, resins and white clay are added to the above mentioned processes depending on final product. Detail list of raw material for each product are given in detail in Tables 5.5 to 5.8.

The raw materials are first hand sorted for impurities and then fed to the hydra pulper where water is added to arrive at the required consistency through the experience of the workers. After this, unwanted material such as pins, clips, sand etc. are separated by means of high density cleaner, riffler and fine screening. Raw water as well as white water is added in the process to get a contiguous flow of the stock. The stock is then fed to a decker where excess water is removed and stored in chests. This water (white water or back water) which is rich in fibre is stored for recycling.

While adding the required quantity of water to the stocks, it is pumped to the paper machine flow box which transmits the stock to the cylinder machine or to the belt in the fourdriner machine where it is evenly distributed on the surface of the mesh or belt. Water is removed initially by gravity draining, followed by suction, pressing and then drying by steam. The final product is rolled into a reel which is transferred to the cutting section where quality controlling, cutting to the required size and packing will take place. The flow diagrams for the each of the production lines are given in Figs. 3.3 to 3.5.

3.3 Existing Water Supply System

Ground water is the main source of water. There are three deep wells to pump 2900 m^3/day. The ground water is used for wire mesh and belt cleaning, as seal water in suction pumps, feed water to the softener, flow cleaning water and for human consumption in the factory as well as in staff housing. Part of softener water is sent through a ultra violet light before using it for drinking purposes. Although the stock preparation is designed to use white water from the process, there are instances when ground water is used. Apart from this, treated water from the effluent treatment

plant (ETP) is used in the PM I and PM II as paper machine shower water. The ground water and treated water distribution diagram is shown in the Fig. 3.6.

3.4 Existing Wastewater Streams

There are two wastewater streams, namely :

a) The wastewater coming from the production which is transmitted to ETP.
b) Storm water and domestic waste (partly) discharged directly to the public canal.

Process wastewater is conveyed to the sump at the effluent treatment plant by a gravity canal. During peak flow hours wastewater pumping is carried out automatically by a by pass pump. Fig. 3.7 illustrates the wastewater distribution system in this factory.

3.5 Existing Effluent Treatment Plant

The effluent treatment plant (ETP) for the factory which is designed for 3500 m^3/day consists of a sump, 2 clarifiers, gravity sludge thickener, 10 sludge drying beds and 3 aerated lagoons.

The wastewater is first collected in a sump which has a hydraulic retention time of 3.5 h. This wastewater is pumped intermittently into two clarifiers consisting of 200 m^3/day, where most of the suspended solids are settled. Alum is added at the inlet of the clarifier. The water coming out through the weirs of the clarifier is transferred to a series of aerated earth lagoons. From the final lagoon part of the water is pumped back to the process, and the remainder is discharged to Chao Phraya river. The detailed flow diagram for the ETP is represented in Fig. 3.8.

The sludge settled in the two clarifiers is pumped batch wise to a sludge thickener. The drain water from the thickener is transferred back to the sump. The thickened sludge is designed to transfer to sludge drying beds, followed by land filling. But in reality it is directly pumped to near by ground.

3.6 Wastewater Characteristics

The average characteristics of the influent (sump) and effluent (Lagoon III) wastewater of Teppattana Paper Mill Co. Ltd. for September 1994, reported by its environmental division is presented in Table 3.1. The results seems to be in agreement with the prevailing discharge standards in Thailand. It is noted that the dissolved solids have reduced from 772 mg/L to 610 mg/L. This is in contradictory since there is no way of reducing dissolved solids from the existing treatment system.

Table 3.1 Wastewater Characteristics of the Teppattana Paper Mill

Parameter	Influent	Effluent
Temperature (^{0}C)	34	28
pH	7.25	7.29
SS (mg/L)	530	7
DS (mg/L)	772	610
DO (mg/L)	3.9	1.7
BOD_5 (mg/L)	155	11

3.7 Energy Consumption

The two major energy inputs to the factory are in the form of steam and electricity. Steam is produced by two boilers, and the steam distribution system is presented in Fig. 3.9. Of the two boilers one operates using saw dust and other using fuel oil. The fuel oil boiler does not operate under normal operation conditions and it is used only during break down of the other. MOHANTY (1991) found that the steam is produced at 700 kPa in two boilers and distributed in a network to operate Yankee and drum dryers. The condensate is conveyed back to the feed water tank. The average electricity demand of the factory is 1200 kW and the load factor is 72% (MOHANTY, 1991).

CHAPTER IV

METHODOLOGY

4.1 Study Program

The study investigations was carried out to investigate the available potentials of cleaner production with a view to reach zero discharge targets. The general research methodology is outlined in Fig. 4.1.

4.2 Data Collection

The investigations were initiated by gathering relevant information from company files. Some of them were readily available with few modifications and some were generated from the factory records. Some of the important information obtained are presented in Appendix A, Table A-1.

4.3 Inplant Monitoring

The initial site survey included a walk around through the entire manufacturing plant in order to gain a sound understanding of all the processing operations and their interrelationships. Then with finer modifications to the existing process flow diagrams, a detailed and correct flow diagrams with inputs and outputs were prepared.

4.4 Material and Energy Balance

A material balance for each stock preparation and paper making process was carried out separately as specified in the Fig. 4.2. The unit scale balance was limited only for the important unit operations. Since there was no possibility of measuring the raw material quantities for different units, it was decided to calculate the amounts using consistency measurements.

In the absence of measurement facilities making an energy balance was difficult. However, a global energy balance was conducted with the help of the available data in the factory.

4.5 Total Water Balance

The flow measurement points for the water balance of the process was decided from the raw water distribution diagram. Apart from that there were instances where water consumption and wastewater generation from floor cleaning, human consumption, lab use etc. Some of these were estimated using standard figures and reaming was categorize as unaccounted flow.

The overall water and wastewater generation were compared with the bench mark figures in the literature.

4.5.1 Water Consumption Measurement

The global ground water pumping and reuse water consumption was obtained from the factory records. Flow measurements for different units were selected using the process flow diagrams. Fig. 4.3 illustrates the factory layout indicating the flow measurement points. Ground water consumption for stock preparation section was obtained using flow meters as shown in Fig. 4.4. The average consumptions were calculated from 7 days of flow measurement records. As there was no possible method of measuring flow for larger diameter pipes in the paper machine area due to high cost for flow meters, it was decided to use the ultra-sonic flow meter for diameters above 50 mm. Here the readings were taken at every 5 minutes interval to calculate the daily consumption figures.

Fig. 4.4 Flow Measurement using Flow Meters

4.5.2 Wastewater flow Measurement

V-notches as presented in Fig. 4.5 were installed for all three paper machines and near the discharge point to the sump. All these V-notches were calibrated before using. The average water levels were obtained from continuous water level measurements for 24 hours. Wastewater generation from stock preparation was measured using a bucket and stop watch. The wastewater flow measurement points are indicated in Fig. 4.6. There were instances of overflow from the back water storage chest in the PM II. Although this was not measured separately, it was estimated using the raw water consumption measurements. The quantity of over flow water from the reuse water storage tanks were found out from the recorded data in the mill.

Fig. 4.5 Flow Measurement Using Weirs

4.6 Chemical Analysis

Chemical analysis depending on the requirement for the purpose was carried out for both raw water and wastewater. All the analysis were carried out at the paper mill laboratory (Fig. 4.7).

4.6.1 Sampling

Raw water sampling points each for ground water, boiler feed water and treated water from the treatment plant were decided as shown in Fig 4.3.

Samples of wastewater from the two drains of each paper machine and centricleaner rejects from each stock preparation unit was obtained. The sampling locations are indicated in Fig. 4.5.

In treatment plant audit, sampling point for each unit operation of the treatment plant was selected.

It was decided reasonable to obtain grab samples for all the sampling operations.

Fig 4.8 Laboratory Analysis of Wastewater

4.6.2 Water and Wastewater characterization

Water samples obtained for each of the unit process as mentioned in section 4.6.1 were analyzed for Temperature, pH, Alkalinity, Chloride and Hardness.

Samples form the wastewater distribution system and treatment plant were analyzed for TS, SS, temperature, COD, BOD and pH.

All the above analysis were conducted according to the standard method of examination for the water and wastewater (APHA, AWWA and WPCF, 1989).

4.7 Effluent Treatment Plant Audit

Observation and analysis as mentioned in the section 4.6 were done on effluent treatment plant (ETP) to understand its operation, current problems and to determine the efficiency of unit operations.

Apart from that a Jar test experiment was carried out in order to find out the optimum Alum dosage for coagulation.

CHAPTER V

RESULTS AND DISCUSSION

5.1 Bench Mark for Teppattana Paper Mill

A preliminary material balance data associated with operation within the paper mill was first drawn up on an overall input/output basis. The daily manufacturing capacity of duplex board (PM I), printing and writing paper (PM II) and glass interleaving paper (PM III) was said to be 30 tonnes, 14 tonnes and 6 tonnes respectively. The management assumed a solid loss of 12%, 10% and 5% respectively from each of the above products. The information is tabulated in Table 5.1.

Table 5.1 Preliminary Material Balance for the Mill

Inputs	tonnes/day
Waste paper and virgin pulp	56
Ground water	2700
Reuse water	1000
Total Inputs	3756

Outputs	tonnes/day
Finish products	50
Solid loss	6
Wastewater	3500
Total Outputs	3560

The preliminary material balance obtained from the information given by the production manager was within 5%-10% range. It was considered that the material balance information was sufficient to meet immediate requirements but it would be useful to carryout further waste audit in order to implement waste reduction measures.

The general information regarding the unit was first collected as presented in Appendix A. The methods adopted to measure various parameters are shown in Appendix B.

5.1.1 Raw Water Used in the Paper Mill

There are two types of raw water used in the mill, namely:

1. Ground water
2. Reuse water (Treated Water from Lagoon III)

Ground water is used in all three paper machines and stock preparation departments, feed water to the softener and for other general purposes. Reuse water is used for wire mesh cleaning in PM I and PM III. The overall raw water consumption of the mill is 89 m^3/tonne of paper.

Comparison of quantity of water used per tonne of paper with standard norms is presented in Table 5.2. It seems that the overall water consumption is about 7 times higher than standard norms. The major reason for this is that most of the equipment are old and outdated. Inadequate instrumentation and controls have necessitated manual control of many important unit operations. This results in high raw water consumption and hence a great deal of wastewater discharge.

Table 5.2 Comparison of Water Consumption with Standard Norms

Teppattana Paper Mill		Standard Norms	
Product	Consumption (m^3/tonne of product)	MYREEN (1994) (m^3/tonne of product)	RAYTHEON ENGINEERS and CONSULTANTS INC. (1995) (m^3/tonne of product)
Duplex Board	58	2-20	12
Printing and Writing Paper	100		
Glass Interleaving Paper	211		

5.1.2 Wastewater from Production Process

The major wastewater contribution is from the paper machine drains. The wastewater from each of the production line was measured qualitatively as well as quantitatively. The overall waste volume discharged from the process is found to be 87 m^3/tonne of paper. The comparison of waste volume and load with ECONOMOPOULOS (1993) standards are presented in Table 5.3.

From the results it seems that the waste volume is within the standard limits yet it is in contradictory when compared with standard raw water consumption figures. The ECONOMOPOULOS (1993) values may be for general mills which adopts the old technology. It is always better to compare it with the new technologies since the ultimate product will have to compete with the similar products in the market. According to MYREEN (1994) the wastewater generated may vary from 5-20 m^3/tonne depending on the product. The overall SS leaving the manufacturing process is found to be 59 kg/tonne of paper and the COD component is 67 kg/tonne of paper. When compared with ECONOMOPOULOS (1993), SS is much higher than the standard. This may be due to the reason that it uses recycle paper as raw material. FOLKE (1994) indicated that the solid waste from recovered paper pulping process may vary from 53 - 667 kg/tonne of paper depending on pulping technology and required characteristics of product. It can be concluded that SS leaving the manufacturing process is within the standard range. This SS can be further reduced by installing a fiber recovery unit. It should be noted that most of the wastewater characteristics are in agreement with the Table 2.3 values adopted form ENERGY MANAGEMENT CENTER (1995).

Table 5.3 Comparison of Wastewater Discharged with Standard Norms

Production	Teppattana Paper Mill		ECONOMOPOULOS (1993)	
	Waste Volume (m^3/tonne of product)	SS (kg/tonne of product)	Waste Volume (m^3/tonne of product)	SS (kg/tonne of product)
Duplex Board	56	60	200	30
Printing and Writing Paper	97	61	190	2
Glass Interleaving Paper	206	54	190	2

5.1.3 Energy Consumption of the Mill

The energy consumption data for the mill was estimated using the available data in the factory. Electrical energy and steam energy are the two main energy sources used in the mill. Saw dust and bunker carbon oil is used to produce steam in the boiler. The comparison of energy consumption with standard norms is presented in Table 5.4.

The electrical energy consumption for stock preparation is comparatively high, whereas for paper machine it is comparatively low. The standard norms are obtained from integrated mills. These paper mills may get pulp in the bladed form and may not require the use of equipment such as hydra pulpers and high density cleaners. On the other hand, it uses recycle paper that contains lot of impurities which have to be removed before conveying it to the paper machine. Thus, it is not reasonable to compare the actual data with the available standard norms. The steam consumption figure is within the accepted range.

5.2 Waste Auditing of the Paper Mill

Figs. 5.1 to 5.5 illustrate the schematic production process flow diagrams for the three different products. The main section that consumes raw water is paper making process. Most of the water required for stock preparation is pumped from the white water (back water) discharged from the paper machine drains. It was noted that the solid waste generated from the production process is almost negligible. The measured quantity of solid waste discharged from the stock

Table 5.27 Proposed Cleaner Production Options

Waste Minimization Measure	Section	Anticipated Benefits	Technical Requirements	Environmental Impact	Implementation Stage	Remarks
Good House Keeping						
Installation of level controllers and retaining walls for Intermediate chests	SP	Reduced product cost Reduced reprocessing	Level Controller Anticipated system retaining walls	Reduces pollution load marginally	I	Measure is easily implementable
Minimizing paper wastage during reeling	U	Reduced paper wastage	Nil	No significant impact	I	Measure is easily implementable
Provision of better reel tension for cutting machine	U	Improved product quality Increased production Reduced energy cost	Pneumatic/ hydraulic/ mechanical wheel type tension to reel holder	No significant impact	II	Indigenously available
Adjustment of paper width by edge cutting nozzles	PM I	Reduced paper trimming loss Reduced reprocessing of paper trimming Marginal reduction in dryer steam consumption	Nil	Nil	I	Instead of cutting the paper to the required size, cutting using edge cutting nozzles Easily implementable
Combustion optimization in boilers	U	Reduced fuel requirement due to reduced stack and unburned losses in ash	Required training of boiler operators to optimize combustion	Reduced air pollution	I	Measure requires improvements in operational practices
Avoidance of condensate and steam leaks	U	Reduced heat loss Reduced make up water requirement	Nil	No significant impact	I	The measure requires timely repair and maintenance
Input Material Chang						
Using Poly Aluminum Silicate (PASS) as sizing material instead of Alum	SP	Improved drainability Increased fibre retention Enables manufacturing of high grammage paper	Nil	Reduced TS in effluent	II	The effectiveness of size is further when PASS is used with cationic polymer

Table 5.27 Continued

Waste Minimization Measure		Anticipated Benefits	Technical Requirements	Environmental Impact	Implementation Stage	Remarks
Better Process Contro	Section					
Consistency indicator	All	Consistency regulation becomes easy Variation in grammage is avoided Reduction in paper breakage Enable uniform paper drying	Consistency Indicator	Marginal reduction in TS at ETP	II	Reduces dependency on human judgment More applicable to small mills
Consistency regulator	All	Consistency regulation becomes easy Variation in grammage is avoided Reduction in paper breakage Enable uniform paper drying	Consistency Regulator	Marginal reduction in TS at ETP	III	More suitable for continuous pulp making The measure is very expensive and economically not viable to small mills
Equipment Modificatior						
Removal of sand inerts from centricleaner wastewater	All	Prevention of sand and inert loading in ETP Reduced wear and tear of pumps in ETP and hence reduced maintenance Prevention of choking of drains	Rifflers	Easy removal of sludge from the clarifier	I	Frequent cleaning of drains is avoided. Easily implementable
Installation of better nozzles in cleaning showers	PM	Reduced water consumption Better cleaning efficiency resulting in better machine runability	Fan flat type or other suitable nozzle in place of existing perforated pipes and simple nozzles	Reduction of effluent volume Difficult to quantify	I	Measure is easily implementable

Table 5.27 Continued

Waste Minimization Measure	Section	Anticipated Benefits	Technical Requirements	Environmental Impact	Implementation Stage	Remarks
Prevention of pulp spillage from paper M/C head box by providing proper positioning guard	PM.	Increased fibre recover Better working conditions	Nil	Reduction in solid loading to ETP	I	Simple and easy to implement Applicable to small mills
Installation of additional press roll set	PM II	Increased Mechanical dewatering Reduced steam consumption in drying Increased speed of paper machine and hence capacity	Press roll Space availability between existing press roll and dryer is a must	Reduced air pollution due to lower steam requirement	III	This measure is applicable only in cases where adequate space is already available
Replacement of conical refiners by double disc (2D) and tri disc (3D) refiners	SP	Reduction in energy consumption	2D and 3D refiners	Reduction in energy consumption	II	Requires further analysis
Recovery and Reuse						
Recovery of fibre from CC rejects	SP	Reduced fibre loss Reduce dependency on operators Reduced pollution load	Fibre saver with high pressure pumps or Hill screens with low pressure pumps	Reduction in TS load by 15%	III	A high pressure pump (HP) of DAF system can be used to supply HP water
Recycle fan pump pit overflow to couch pit or providing level controller	PM	Reduced fibre loss Reduced dilution requirement in couch pit	Small pipe line. The flow can be taken by gravity. The level controller should actuate and control the fresh water supply	Reduction in COD and TS load but difficult to quantify	I	The measure is very simple and easy to implement

Table 5.27 Continued

Waste Minimization Measure	Section	Anticipated Benefits	Technical Requirements	Environmental Impact	Implementation Stage	Remarks
Recycle of vacuum pump seal water for wire mesh and belt cleaning	PM	Reduced fresh water consumption	High pressure pumps	Reduced load to the treatment plant	III	Requires further analysis since the pressure inside the separator tank is below atmospheric
Recovery of flash steam	U	Improved condensate recovery. Marginal reduction in energy utilization	Heat exchanger	Reduction in energy consumption	II	Heat can be exchange with make up water. This will de-aerate make up water
Save all for fibre recovery followed by filtration using micro filters	PM	Increased fibre recovery Reduced pollution load Reduced effluent volume Filtrate can substitute fresh water consumption in SP section and PM section	Dissolved air floatation (DAF) unit Additional poly electrolyte consumption Skilled man power required for DAF	Reduced in TS by 5%	I	The system is more energy and chemical intensive but gives higher fibre recovery and raw water saving. Pay back period for the investment is 3 years

preparation department is presented in Table C-31 in Appendix C. Frequent breakage of paper is one of the major draw back in the system.

Table 5.4 Comparison of Energy Consumption with Standard Norms

Process	Teppattana Paper Mill		Standard Norms	
	Electrical Energy (kWh/tonne of paper) (SRIPADIT, 1990)	Steam (tonnes/tonne of paper)	Electrical Energy (kWh/tonne of paper) (AHUJA and BIHANI, 1990)	Steam (tonnes/tonne of paper) (CHANDAK et al., 1995)
Stock Preparation	317		164-175	
Paper Machine	240	2.0	410-415	2.0
Utilities	101		160-165	

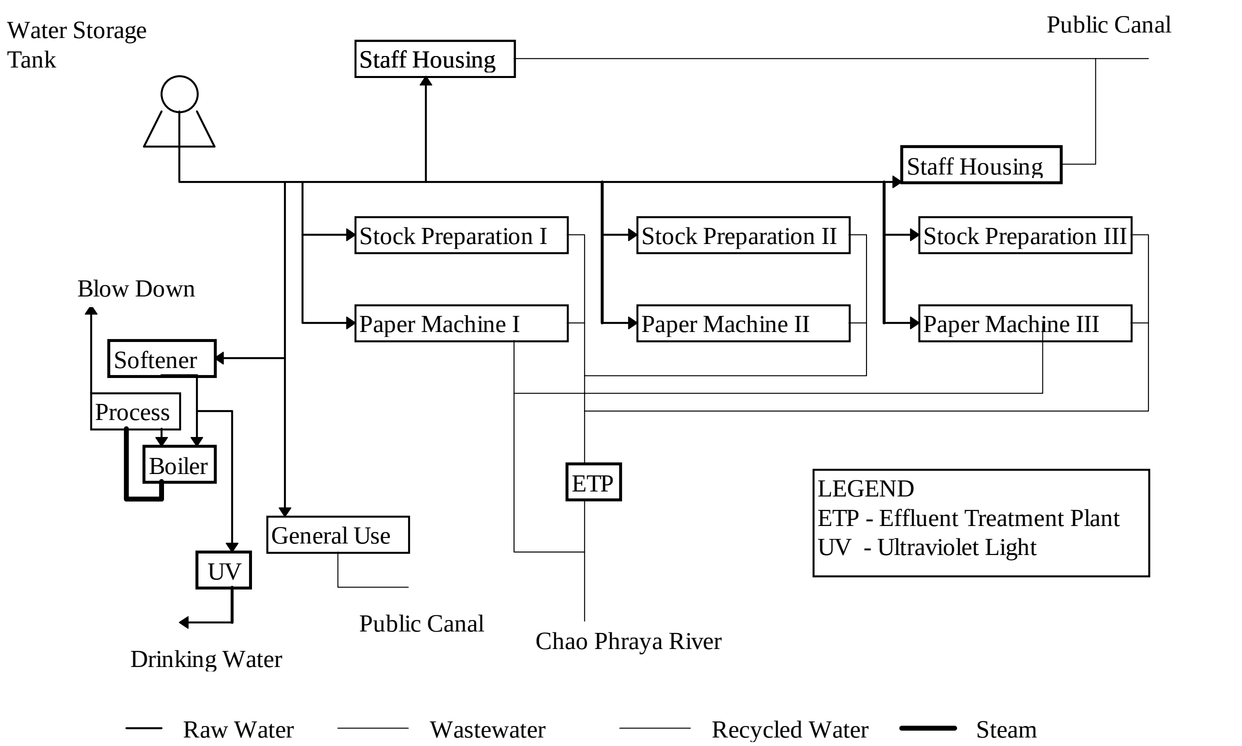

Fig. 5.6 Flow Diagram for Water Usage and Wastewater Discharge

Fig. 5.6 illustrates the simplified flow diagram indicating allocation of water for one use to another and wastewater discharge in this factory

5.2.1 Input Material and its Cost Analysis

The input materials and its cost figures for the three different products are presented in Tables 5.5 to 5.8. The average total production for the year 1995 was found to be 42.03 tonnes/day. This consist of 25.34 tonnes/day of duplex board, 11.22 tonnes/day of printing and writing paper and 5.47 tonnes/day of glass interleaving paper. The monthly production for the year 1995 is presented in Fig. 5.7. During high demand periods for glass interleaving paper, PM II is converted from printing and writing paper to glass interleaving paper at an average capacity of 4.62 tonnes/day. The grammage of paper varied depending on the market requirements. The average grammage for duplex board, printing and writing paper and glass interleaving paper is 310 g/m^2, 70 g/m^2 and 35 g/m^2 respectively.

Though the factory records say that for duplex board it uses 43% waste magazines, 43% card board boxes and 14% white paper, the actual proportion was found to be 21% magazines, 52% card board boxes and 21% white paper. The deviation from the expected values was due to the availability of raw material in the market. For printing and writing paper the proportion of virgin pulp and white paper was found to be 38.6% and 61.4% respectively which is in agreement with the expected figures.

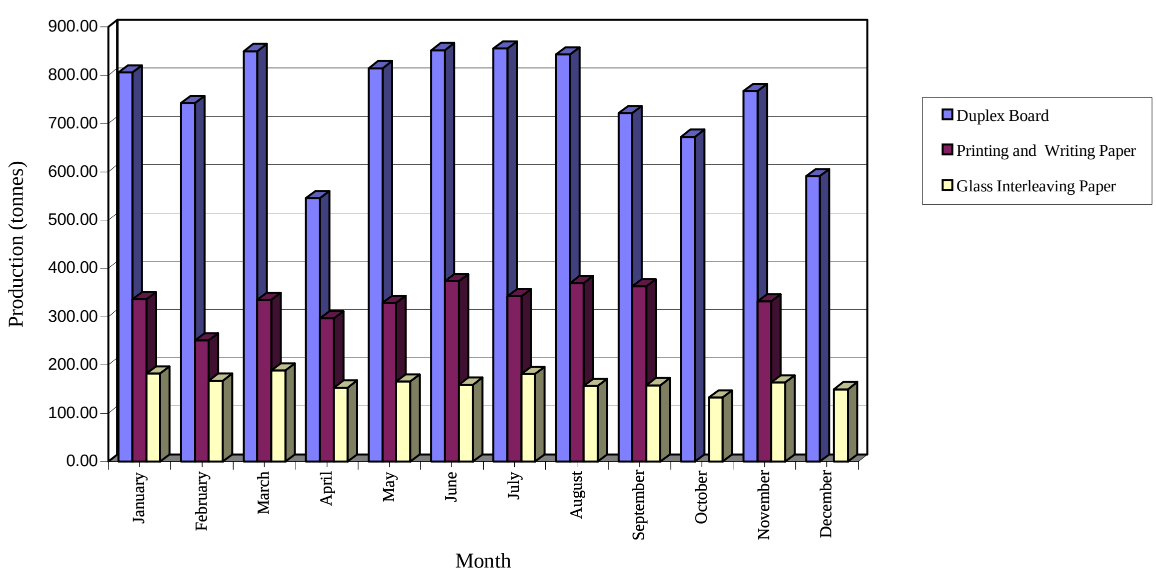

Fig. 5.7 Monthly Production for the Year 1995

A comparison of actual raw water consumption and electricity consumption figures with the factory estimated figures are tabulated in Table 5.9. It is noted that the management has not allocated any cost for reuse water consumption. It is advisable to allocate at least the treatment cost as cost for reuse water.

Table 5.5 Input Material Cost for Duplex Board (PM I)

Input Material	Cost/ton ($)	Average Monthly Consumption (tons)	Consumption per ton of Paper (10^{-3} tons)	Cost/ton of Paper ($)
Pulp				
CPO	320.00	9.1	12.0	3.84
Card Board Box	152.00	440.2	582.0	88.46
Magazines	112.00	125.8	167.7	18.78
White Pound Paper	440.00	171.7	227.1	99.92
Colorful Pound Paper	112.00	96.2	127.2	14.25
Other Waste Paper	227.20	1.6	2.1	0.48
Chemicals				
Alum	168.00	21.8	28.8	4.84
Sown-glue Honor-650	720.00	6.1	8.1	5.83
Bleaching Reagent	4,000.00	0.15	0.4	0.80
Deformer	2,000.00	0.48	0.2	0.80
Modified Starch	600.00	0.31	0.6	0.36
Wax	1,137.60	0.23	0.3	0.40
PVA	4,040.00	0.24	0.3	1.21
Violent Tint	10,800.00	0.005	0.006	0.06
Others				
Ground Water	0.105 $/m^3$	50,621 m^3	67 m^3/ton	7.04
Reuse Water	-	27,337 m^3	37 m^3/ton	-
Power	0.0625 $/kWh	488,957 kWh	646.7 kWh/ton	40.41
Saw Dust	19.32	418.65	0.554 tons/ton	10.70
Total Cost of Input Raw Material				279.91

Note : CPO - Computer Paper
PVA - Poly Vinyl Alcohol

Table 5.6 Input Material Cost for Printing and Writing Paper (PM II)

Input Material	Cost/ton ($)	Average Monthly Consumption (tons)	Consumption per ton of Paper (10^{-3} tons)	Cost/ton of Paper ($)
<u>Pulp</u>				
Virgin Pulp	560.00	141.0	424.7	237.83
White Pound Paper	440.00	213.6	643.3	283.05
CPO	320.00	10.3	31.0	9.92
<u>Chemicals</u>				
Alum	168.00	15.7	47.3	7.95
Kaolin	178.00	9.7	29.2	5.20
Bleaching Reagent	4,000.00	0.4	1.2	4.80
Deformer	2,000.00	0.4	1.2	2.40
Emulsion Size 311	380.00	13.2	39.8	15.12
Antiseptic	2,200.00	0.09	0.3	0.66
Violent Tint	10,800.00	0.009	0.027	0.29
<u>Others</u>				
Ground Water	0.105 $\$/m^3$	21,488 m^3	64.7 m^3/ton	6.79
Power	0.0625 $/kWh	488,957 kWh	559.0 kWh/ton	34.93
Saw Dust	19.32	418.65	0.536 tons/ton	10.42
Total Cost of Input Raw Material				619.36

Table 5.7 Input Material Cost for Glass Interleaving Paper (PM II)

Input Material	Cost/ton ($)	Average Monthly Consumption (tons)	Consumption per ton of Paper (10^{-3} tons)	Cost/ton of Paper ($)
<u>Pulp</u>				
Proof Waste Paper	400.00	143.2	1,052.9	421.16
<u>Chemicals</u>				
Alum	168.00	11.62	85.4	14.35
HCl	200.00	1.5	22.2	2.24
Deformer	2,000.00	0.36	2.6	5.20
Antiseptic	2,200.00	0.013	0.09	0.20
<u>Others</u>				
Ground Water	0.105 $\$t/m^3$	11,541 m^3	84.83 m^3/ton	9.06
Power	0.0625 $/kWh	156,055 kWh	1147 kWh/ton	71.68
Saw Dust	19.32	90.6	0.666 tons/ton	12.87
Total Cost of Input Raw Material				536.76

Table 5.8 Input Material Cost for Glass Interleaving Paper (PM III)

Input Material	Cost/ton ($)	Average Monthly Consumption (tons)	Consumption per ton of Paper (10^{-3} tons)	Cost/ton of Paper ($)
Pulp				
Proof Waste Paper	400.00	171.3	1,050.2	420.08
Chemicals				
Alum	168.00	8.3	50.9	8.55
HCl	200.00	2.6	15.9	3.18
Deformer	2,000.00	1.36	2.2	4.40
Antiseptic	2,200.00	0.09	0.6	1.32
Others				
Ground Water	0.105 $\$/m^3$	11,022 m^3	67 m^3/ton	7.10
Reuse Water	-	4,031 m^3	25 m^3/ton	-
Power	0.0625 $/kWh	128,251 kWh	786.2 kWh/ton	49.12
Saw Dust	19.32	90.2	0.553 tons/ton	10.68
Total Cost of Input Raw Material				504.43

Conversion Rate : 1 $ = 25.00 Baht on 23/07/96

The actual electrical energy consumption figures are less than the estimated figures for duplex board and printing and writing paper. This may be due to the fact that the management does not consider the electricity cost for utility section as a separate cost. For glass interleaving paper the actual value is comparatively high due to the outdated equipment used in the process and the low grammage of paper.

Table 5.9 Comparison of Actual Input Data with the Factory Estimated Figures

Product	Raw Water (m^3/tonne of product)		Electricity (kWh/tonne of product)	
	Factory Estimation	Actual	Factory Estimation	Actual (SRIPADIT, 1990)
Duplex Board	104	58	647	525
Printing and Writing Paper	85	99	559	407
Glass Interleaving Paper	92	211	786	990

5.2.2 Recording for Water Usage

In this study the water consumption for stock preparation, paper machine, softener and staff housing were measured separately. The measurement of raw water consumption records for different sections of the mill is tabulated from Tables C-1 to Table C-15 in Appendix C. In some months reuse water consumption varied rapidly due to malfunctioning of the floater valves. In order to find out the average values, the abnormal numbers were neglected. The total ground water and reuse water consumption on monthly basis as well as daily basis was obtained from the factory records. The average monthly consumption of ground water and reuse water was found to be 84,264 m^3 and 31,368 m^3 respectively. The average monthly raw water consumption was found to be little lower than the calculated value from the daily average figures under normal operating conditions. This may be due to holidays and break down of machines. Therefore it was decided reasonable to use daily average figures for further calculations. Water consumption for PM III (Glass Interleaving Paper) was obtained using the water balance as shown in Appendix D Table D-1 since there was no other possibility of measuring the same. The value obtained was confirmed correct with the measurement of wastewater discharge. Table 5.10 represents the summary of water balance in the mill. The break up of water consumption for each of the production lines is presented in Appendix D Tables D-1 and D-2. It was found that there is an imbalance of 130 m^3/day (3% of total water input). This is due to the consumption of water for lab, flow cleaning, machine cleaning and other accidental losses.

Characteristics of different types of raw water used in the mill are presented in Appendix C Tables C-51 to C-53. The raw water quality for reuse water is as same as given in Table C-49 in Appendix C for Lagoon III. The summary of the raw water characteristics and comparison with standards are presented in Table 5.11.

Water quality of the mill was well within the acceptable limits except for dissolved solids present in reuse water and hardness in ground water. According to standards the total solids that can be present in fine paper is 210 mg/L whereas the actual figure comes around 851 mg/L for reuse water. Hardness should be less than 100 mg/L and the actual figure is 225 mg/L. Further studies have to be conducted in order to find out the effects of these to the production process.

Table 5.10 Raw Water Balance of the Mill

Raw Water input

Description	Quantity (m^3/day)
Ground Water	2890
Reuse Water	1121
Total	4011

Raw Water Consumed

Description	Quantity (m^3/day)
Duplex Board	1459
Printing and Writing Paper	1119
Glass Interleaving Paper	1156
Softener Feed Water	24
Staff Housing	100
Human Consumption : Sanitary (25L/day.person)	4.5
Plant (75L/day.person)	18
Total	3880.5

Note : Water for human consumption is estimated from METCALF and EDDY (1991) and RAYTHEON ENGINEERS and CONSULTANTS INC. (1995).

Table 5.11 Comparison of Raw Water Quality with Standard Values

Type	Temp (^{0}C)		pH		Total Alkalinity (mg/L)		Chloride (mg/L)		Hardness (mg/L)		TS (mg/L)	
	T	S	T	S	T	S	T	S	T	S	T	S
Ground Water	36	-	7.26	-	195	40-75	76	-	224	100	460	-
Reuse water	32	-	7.29	-	-	40-75	-	-	-	-	851	210
Boiler Feed water	85	-	7.92	8.00	75	-	28	250	12	80	-	-
Drinking water	39	-	7.44	6.5-8.5	175	-	81	-	31	300	384	500

Note : T = Teppattana Paper Mill

S = Standard Norms

Source:

Drinking Water : ENVIRONMENTAL QUALITY STANDARDS DIVISION (1989)

Raw Water : CANADIAN COUNCIL OF RESEARCH AND ENVIRONMENTAL MINISTRIES (1987), as cited by LEEDEN, F., TROISE, F.L., TODD, D.K. (1990).

Boiler Feed Water : AMERICAN WATER WORKS WATER QUALITY CONTROL AND TREATMENT, NEW YORK (1950) and WATER QUALITY CONTROL, CALIFORNIA (1963), as cited by LEEDEN, F., TROISE, F.L., TODD, D.K. (1990).

5.2.3 Accounting for Total Wastewater

The major process output of concern was liquid waste from the paper machine. The measurement of wastewater discharged from the process is represented in Appendix C Tables C-24 to C-30. Wastewater discharge from the three paper machines obtained using weirs and 24 hour continuous water level measurements under normal operation days except for PM I drain I. In PM I drain I, the average level was obtained using 6 hours of continuous water level measurements due to some practical difficulties. Wastewater discharged from the stock preparation process was measured using bucket and stop watch method. Since the stock preparation process is a batch operation it was decided to take an average time of operation per one day in order to find out the daily flow of wastewater. The hour meter measurements obtained for this purpose are presented in Appendix C Tables C-21 to C-23. Qualitative analysis of wastewater for the two different sections, stock preparation and paper machine was carried out in the paper mill laboratory and data obtained are presented in Appendix C Tables C-37 to C-44. Table 5.12 gives the summary of the wastewater balance. Table 5.13 illustrates the total water balance.

Table 5.12 Wastewater Balance

Description	Quantity (m^3/day)
Total raw water consumption	4011
less : Staff housing	100
Softener	24
Human Consumption (Sanitary)	5
Amount Evaporated	70
Expected Amount of Wastewater	3812
Measured Quantity of Wastewater	4027

The difference in raw water used and wastewater generated could be due to:

- The average reuse water consumption for the four days of flow measurement was 1500 m^3/day as presented in Appendix C Table C-34 , but the average value taken for calculation was 1121 m^3/day. This leads to an excepted flow of 4191 m^3/day. But the measured average was 4027 m^3/day that gives a difference of 164 m^3/day (4% from the expected value). This difference may be due to the conveyance and evaporation losses in the system and general raw water use which is conveyed directly to the public canal.

- For further calculations measured value of wastewater discharged was taken as 3648 m^3/day.

It was noted from the flow measurements in Appendix C that the wastewater generated from PM I is higher than the raw water input. The difference is 32 m^3/day. In addition about 38 m^3/day is evaporated by giving a total imbalance of 70 m^3/day. This may be due to some abnormal increment of water use. Therefore for future analysis waste volume was taken as 1344 m^3/day.

The quality of wastewater measured at different points of the process are presented in Appendix C Tables C-37 to C-44. The summary of the waste stream analysis is presented in Table 5.14.

Filtered COD values for stock preparation was measured since it contained sandy particles and high concentration of suspended matter. Although the wastewater coming from stock preparation is small, it contains high pollution load. In some occasions it was found that there is very high amount of total solids from centricleaner rejects. It is advisable to separate this wastewater from the main stream and directly convey it to the thickener. Apart from stock preparation, PM I Drain I contribute very much for high pollution. This is mainly because of waste paper used in the process. The pH of wastewater coming from glass interleaving paper is low due to the fact that it uses sulfuric acid in the production line.

It is noted that, vacuum pump suction lines contain SS (PM I Drain II). This is because they are piped directly from the suction point to the vacuum pump. Fibre and hot water thus go directly into the vacuum ring pump so that fibre is discharged to the sewer and capacity of the pump is reduced. The proper of way pipe up is to run the suction line into a separate tank and then to a seal pit.

Table 5.13 Total Water Balance of the Mill

Operation	Raw Water Use (m^3/day)	Wastewater (m^3/day)
PM I	1389	1344
SP I	70	77
PM II	917	953
SP II	202	46
PM III	1069	1039
SP III	87	87
Total	3734	3546

The difference in fresh water and wastewater generated could be due to,

- Steam vapor formed during drying = 70 m^3/day
- Unaccountable losses such as evaporation, conveyance losses, over flow of white water storage tanks (PM II) and accidental losses =116 m^3/day (3%).
- For further calculations the wastewater from PM II was calculated to 1053 m^3/day assuming an evaporation loss of 20 m^3/day.

Table 5.14 Waste Stream Analysis

Wastewater Source	Flow (m^3/day)	Temp. (C^0)	pH	SS (mg/L)	TS (mg/L)	DS (mg/L)	COD (mg/L)
PM I Drain I	1127	34.9	6.75	994	2161	1164	1282
PM I Drain II	217	36.8	7.38	29	430	400	59
PM II Drain I (P&W)	653	38.1	6.97	398	1239	841	430
PM II Drain II (P&W)	442	38.1	7.19	315	997	682	267
PM III Drain I	350	34	6.78	163	610	440	221
PM III Drain II	776	36	6.55	291	946	660	392
PM II Drain I (GI)	653	37.4	5.13	402	1049	646	418 (F)
PM II Drain II (GI)	442	34.3	6.59	135	535	424	102 (F)
SP I	77	34	7.00	5035	6393	1358	44 (F)
SP II (P&W)	46	40.7	5.97	7855	9422	1567	308
SP III	87	34.6	4.81	1581	2399	832	109
SP II (GI)	46	38.5	4.27	4671	6239	1576	76 (F)

Note: F = Filtered COD

GI = Glass Interleaving paper

P&W = Printing and writing paper

Wastewater from SP III is included in PM III drain II qualitatively as well as quantitatively.

5.2.4 Evaluating Material Balance

A material balance of input and output across the two sections of the paper making process was made and presented in Tables 5.15 to 5.18. The initial moisture content of raw material was assumed to be 5% in all the analysis (FOLKE, 1994). Almost all the water required for stock preparation is obtained from the paper machine drain water (back water). Since this water contains high amount of SS it was not possible to measure it using normal flow meters. Therefore it was decided to measure the consistency as presented in Appendix C Tables C-16 to C-19 in order to complete the material balance. The average amount of input raw material was obtained from the purchase records of the factory. The solid waste generated from the process was almost negligible and measured values are presented in Appendix C Table C-31.

Table 5.15 Overall Material Balance for Duplex Board (PM I)

Unit Operation/ Department	Input Material (TPD)							Output Material (TPD)							Other Streams (TPD)							
	Name	Overall			Solids			Name	Overall			Solids			Name	Type	Overall			Solids		
		A	BC	D	A	BC	D		A	BC	D	A	BC	D			A	BC	D	A	BC	D
<u>Stock Preparation</u>																						
Hydra Pulper	Recycled Paper	6.05	14.75	7.49	5.76	14.01	7.11	Pulp	195.26	378.41	158.91	5.99	14.8	7.44								
	B/W	189.20	363.66	151.42	0.23	0.79	0.33															
Riffler	Pulp	195.26	378.41	158.91	5.99	14.8	7.44	Pulp	621.15	531	293.19	6.4	14.97	7.65	S/R	Solid	0.1	0.2	0.1	0.1	0.2	0.1
	B/W	426.01	152.59	134.28	0.53	0.33	0.29															
Fine Screen (OT)	Pulp	621.15	531	293.19	6.4	14.97	7.65	S/P	621.15	940.08	458.08	6.4	17.02	8.47								
	C/C		409.08	164.89		2.05	0.82															
Centricleaner	S/P	621.15	940.08	458.08	6.4	17.02	8.47	C/P	710.65	694.67	247.62	6.47	15.28	7.4	W/W	Liquid	11.92	13.48	51.91	0.06	0.07	0.26
	B/W	101.42	177.15	6.34	0.13	0.38	0.01	O/T		409.08	164.89		2.05	0.82								
Decker	C/P	710.65	694.67	247.62	6.47	15.28	7.4	D/W	210.19	441.08	209.05	6.6	14.73	7.32								
	Chemicals				0.75			B/W	500.46	258.59	38.57	0.62	0.55	0.08								
<u>Paper Machine</u>																						
Stuff Box	D/W Pulp	210.19	441.08	209.05	6.6	14.73	7.32	D/P	2382.4	3588.7	1789.1	9.29	21.53	10.73								
	B/W	2172.21	3147.57	1580.02	2.69	6.8	3.41															
Forming Section	W/M	2100.86	3588.65	1789.07	9.29	21.84	10.73	Paper	151.63			25.63			W/W	Liquid	1127			1.48		
	R/W	1299						B/W	7498.9			14.75										
Press Section	Paper	151.63			25.63			Paper	66.23			25.57										
	R/W	160						B/W	28.42			0.06										
Dry Section	Paper	66.23			25.57			Paper	26.39			25.57			Steam	Vapor	39.8					

Note: It was assumed that the rejects from the second centricleaner has a consistency of 0.5% in both line D and BC

Table 5.16 Overall Material Balance for Printing and Writing Paper ((PM II)

Unit Operation/ Department	Input Material			Output Material			Other Streams				
	Name	Qty (TPD)		Name	Qty (TPD)		Name	Type	Qty (TPD)		
		Overall	Solids		Overall	Solids			Overall	Solids	Liquid
Stock Preparation (SP II)											
Hydra Pulper	Recycle Paper	7.51	7.13	Pulp	224.9	7.40					
	Back Water	217.39	0.27	Virgin Pulp	128.44	4.55					
Hydra Pulper	Virgin Pulp	4.73	4.49								
	Ground Water	123.71	0.06								
Mixing Chest SP 20207	Pulp	224.9	7.4	Pulp	248.17	7.37	Screen Reject	Solid	0.06	0.06	
	Back Water	23.27	0.03								
Johnson Screen	Pulp	248.17	7.37	Screened Pulp	622.57	7.78					
	Ground Water	66.00	0.03								
	Back Water	308.4	0.38								
Centricleaned Pulp	Screened Pulp	622.57	7.78	CC Pulp	561.01	7.68	Wastewater	Liquid	61.82	0.10	61.81
Decker	C/P	561.01	7.68	Dewatered Pulp	203.28	7.24					
				Back Water	357.73	0.44					
Mixing Chest SP21101	D/W Pulp	203.28	7.24	Mixed Pulp	331.72	11.79					
	Virgin Pulp	128.44	4.55								
SP 20201	Dewatered Pulp	331.72	11.79	Blended Pulp	397.77	13.19					
	Chemicals		1.32								
	G/W	12.00	0.01								
	Back Water	54.04	0.07								
Paper Machine											
Centricleaner (Stuff Box)	Blended Pulp	397.77	13.19	Pulp	3026.93	15.13	Wastewater	Liquid	38.00	1.36	
	Back Water	2667.16	3.30								
Forming Section	Pulp	3026.93	15.13	Paper	53.11	10.73	Wastewater	Liquid	1053	1.30	
	Raw Water	917.00	0.42	Back Water	2808.66	3.52					
Press Section	Paper	53.11	10.73	Paper	23.66	10.69					
				Back Water	29.45	0.04					
Dry Section	Paper	23.66	10.69	Paper	11.17	10.69	Steam	Vapor	12.52		

Note: Assume solid loss in first Centricleaner as 1581 mg/L

Table 5.17 Overall Material Balance for Glass Interleaving Paper ((PM II)

Unit Operation/ Department	Input Material			Output Material			Other Streams				
	Name	Qty (TPD)		Name	Qty (TPD)		Name	Type	Qty (TPD)		
		Overall	Solids		Overall	Solids			Overall	Solids	Liquid
Stock Preparation											
Hydra Pulper	Recycle Paper	4.77	4.53	Pulp	197.16	4.73					
	Back Water	192.39	0.20								
Mixing Chest SP 20207	Pulp	197.16	4.73	Pulp	265.27	4.80	Screen Reject	Solid	0.01	0.01	
	Back Water	68.11	0.07								
Johnson Screen	Pulp	265.27	4.8	Screened Pulp	588.34	5.06					
	Ground Water	66.00									
	Back Water	257.07	0.27								
Centricleaned Pulp	Screened Pulp	588.34	5.06	C/P	549.26	5.00	Wastewater	Liquid	39.08	0.06	
Decker	C/P	549.26	5.00	Dewatered Pulp	188.64	4.62					
				Back Water	360.62	0.38					
Mixing Chest SP 20201	Dewatered Pulp	188.64	4.62	Blended Pulp	200.40	5.08					
	Chemicals		0.45								
	G/W	11.76									
Paper Machine											
Centricleaner (Stuff Box)	Blended Pulp	200.40	5.08	Pulp	1757.24	6.53	Wastewater	Liquid	38.00	0.18	
	Back Water	1556.84	1.63								
Forming Section	Pulp	1757.24	6.53	Paper	24.06	4.23	Wastewater	Liquid	1053	0.62	
	Raw Water	917.00		Back Water	1597.18	1.68					
Press Section	Paper	24.06	4.23	Paper	14.96	4.22					
				Back Water	9.10	0.01					
Dry Section	Paper	14.96	4.22	Paper	4.36	4.22	Steam	Vapor	10.60	_	_

Note: Assume solid loss in first centricleaner as 1581mg/L from SP III.

Table 5.18 Overall Material Balance for Glass Interleaving Paper (PM III)

Unit Operation/ Department	Input Material			Output Material			Other Streams				
	Name	Qty (TPD)		Name	Qty (TPD)		Name	Type	Qty (TPD)		
		Overall	Solids		Overall	Solids			Overall	Solids	Liquid
Stock Preparation Hydra Pulper	Recycle Paper Back Water	5.74 133.92	5.45 0.08	Pulp	139.66	5.53					
Mixing Chest SP 30206	SP 30206 G/W	139.66 43.67	5.53	Refined Pulp	183.33	5.50	Screen Reject		0.03	0.03	
3F Screen	Refined Pulp Back Water	183.33 35.77	5.50 0.02	Screened Pulp	219.10	5.52					
Centricleaned Pulp	Screened Pulp Back Water	219.10 96.61	5.52 0.06	C/P	315.71	5.51	Wastewater	Liquid	31	0.07	30.93
Decker	C/P	315.71	5.51	D/W Pulp Back Water	211.98 103.73	5.45 0.06					
Mixing Chest SP 30201	D/W Pulp Chemicals G/W	211.98 10.16	5.45 0.37	Blended Pulp	222.14	5.82					
Paper Machine Stuff Box	Blend Pulp Back Water	222.14 775.53	5.82 0.47	Pulp	997.67	6.29					
Forming Section	Pulp Raw Water	997.67 1067	6.29	Paper Back Water	74.83 863.84	5.54 0.53	Wastewater	Liquid	1126	0.22	
Press Section	Paper	74.83	5.53	Paper Back Water	24.23 50.60	5.50 0.03					
Dry Section	Paper	24.23	5.50	Paper	5.73	5.50	Steam	Vapor	18.50	_	_

Legend for Tables 5.15 to 5.18

B/W	- Back water from paper machine drain	W/M	- Wire mesh
S/P	- Screened pulp	R/W	- Raw water
C/P	- Centricleaned pulp	S/R	- Screen reject
D/W	- Dewatered pulp	G/W	- Ground water
O/T	- Open tank	C/C	- Centricleaner

In evaluating the material balance for PM I (duplex board), part of the chemicals (0.23 tonnes/day) used in the paper machine was considered negligible. From the above results it was noted that production quantity is 26.39 tonnes/day whereas from the actual figures it was 25.34 tonnes/day (-4% deviation from the actual quantity). The difference could be due to accidental losses from paper machine stuff box and solid waste generated from the sorting operation.

For PM II (printing and writing paper), the calculated average value was 11.14 tonnes/day where as the actual value was 11.22 tonnes/day (1% deviation from the actual quantity).

In PM II (glass interleaving paper), the calculated average value of paper for one day is 4.36 tonnes/day whereas the actual should be 4.62 tonnes/day (6% deviation from the actual quantity).

For PM III (glass interleaving paper), the calculated quantity of final product was 5.73 tonnes/day whereas the actual value was 5.47 tonnes/day (-5% deviation from the actual quantity).

The moisture content of paper after press section for duplex board (PM I), printing and writing paper (PM II) and glass interleaving paper (PM III) was found to be 61%, 55% and 77% respectively as shown in Table C-20 in Appendix C. According to literature the moisture content after press section would vary from 55% to 70%. Therefore additional press roll is important for PM III in order to reduce steam consumption at the dryer section.

5.2.5 Summary

The water consumption on an overall basis was found to be 89 m^3 per tonne of paper produced. Under normal operation conditions, this figure is about 7 times higher than the standard norms. It would have increased further if it had considered the over flow of raw water from storage tanks due to poor house keeping practices (Appendix C, Table C-1).

The input raw material amounts estimated by the management was found to be varied considerably from the actual figures. This will effect in arriving at the net profit of each product.

The SS leaving the manufacturing process is found to be 59 kg/tonne of paper. This figure is within the accepted limits for a secondary fibre mill. The possibility of recycling this fiber must be studied separately since the fiber lengths may be small compared with the required size due to the use of secondary fiber in the production process.

5.3 Energy Auditing of the Mill

The data for the energy audit of the mill was obtained as far as possible from the available data in the factory. The two major energy inputs to the factory are in the form of steam and electricity. The energy consumption pattern of the mill is 26% electricity and 74% saw dust. Bunker carbon oil and saw dust are used to produce steam. The cost break down for electricity and fuel is found to be 81% and 19% respectively. Specific production cost for electricity and fuel is 41.6 $/tonne of paper and 11.28 $/tonne of paper. MOHANTY (1991) found that the cost allocations for electricity and fuel as 40 $/tonne of paper and 16 $/tonne of paper respectively. It indicates that the fuel cost has reduced by 4.72 $/tonne of paper. This may be due to his recommendations for condensate recovery. He estimated a reduction of 2.56 $/tonne of paper. The remaining may be due to the line distribution improvements in the system and terminating of fuel preheating system adopted earlier.

5.3.1 Consumption of Electrical Energy

The monthly electrical energy consumption of the mill is listed in Appendix C Table C-35. It gives an average daily consumption of 26522 kWh. The average power factor for 3 days of hourly measurement was found to be 0.97. SRIPADIT (1990) measured the hourly electricity load at different sections of the factory. The data obtained for one day is presented in Table C-36. It gives an average daily consumption of 27576 kWh giving a deviation of 4% from the present value. This may be due to the changes in the system and power factor improvements and it was considered that the above figures are accurate enough for further studies. According to this data, the electrical energy consumption for the three different products is presented in Table 5.19. The overall electrical energy consumption is 631 kWh/tonne of paper. MOHANTY (1991) indicated that it varies in the range from 650 - 700 kWh/tonne of paper. This indicates that the electrical energy consumption has not improved considerably for the last 5 years. It is recommended to improve this system since it consumes 80% of the total energy cost. For utilities the electrical energy consumption is 86.4 kWh/tonne of product. Though the factory operates 24 hours a day, throughout the year the hourly average load factor is 68%. The annual peak electricity demand for the year 1995 was 1640 kW. Stock preparation operations are intermittent and there is a possibility of scheduling them in order to avoid the coincident of peak. This is confirmed possible by the operation time measurements in Tables C-21 to C-23 in Appendix C.

The data indicates that for glass interleaving paper the electrical energy consumption is comparatively high. One reason for this may be due to use of conical refiners in the stock preparation department. In many instances it was noted that over capacity pumps were used in the mill. One example is the pump used to discharge wastewater to the sump. The capacity of this pump is found to be 210 m^3/h resulting an operating time of less than 5 minutes at a time. Similarly the pumps providing pulp to the paper machine are oversized and a considerable quantity of pulp pumped overflow and returns to the same reservoir where it is pumped. Finally it is very important to install meters for each and every section and monitor them regularly to find any abnormal consumptions.

Table 5.19 Electrical Energy Consumption for the Three Products (SRIPADIT, 1990)

Product	Stock Preparation (kWh/tonne of product)	Paper Machine (kWh/tonne of product)	Total (kWh/tonne of product)
Duplex Board	304	221	525
Printing and Writing Paper	197	214	411
Glass Interleaving Paper	604	386	989

5.3.2 Consumption of Steam Energy

Saturated steam for the process drying is produced by two steam boilers. The first is of 8 tonnes/h capacity with saw dust as its main fuel and operates for 24 hours a day. The average moisture content of saw dust was found to be 21%. The calculated heat requirement to evaporate this moisture is 0.5% of the total heat input. The other boiler is 6 tonnes/h capacity and it uses bunker carbon oil as its fuel. This boiler is not operated under normal operating conditions. The average steam production for the year 1995 was found to be 3.6 tonnes/h. The steam energy consumption figures for the different products as per SRIPADIT (1990) are illustrated in Table 5.20. According to these figures overall steam consumption is 2.18 tonnes/tonne of paper indicating a 9% reduction from the present data. This may be due to the improvements in condensate recovery and line distribution system.

The steam produced at 700 kPa pressure and distributed in a net work to operate Yankee and drum dryers at 355 kPa. The process steam consumption was found to be 2 tonnes per tonne of paper produced which is within the standard norms. From the data obtained, the feed water to the boiler is found to be 85 tonnes/day and make up water is 23 tonnes/day (assuming 4L/person.day for drinking purposes). If we assume a blow down of 5% (4.25 tonnes/day), 22% (18.75 tonnes/day) of condensate is not returning to the boiler. This should be improved closer to 0% (RAGAN, 1990). One way of improving this is to recover the flash steam. Although MOHANTY (1991) has proposed this, it is still unimplemented. The boiler efficiency is calculated to be 79% as illustrated in Appendix E Table E-4. According to RAYTHEON ENGINEERS and CONSULTANTS INC. (1995) the boiler efficiency should be increased at least to 85%. If it can achieve this target, it will reduce the fuel saving by 11%. There were instances where insulation is damaged in steams pipings and condensate recovery pipe lines. The evaporator bodies are uninsulated. The insulation of evaporator bodies, proper maintenance of line distribution net work and reduction in moisture content in saw dust would improve the steam consumption efficiency.

Table 5.20 Steam Energy Consumption for the Mill (SRIPADIT, 1990)

Process	No of Dryers	Working Hours	Pressure (kPa)	Steam Consumption (tonne/tonne of product)
Duplex Board	16	24	365	2.6
Printing and Writing Paper	2	24	355	1.4
Glass Interleaving Paper	1	24	355	1.8
Stock Preparation II	-	1	-	Negligible

5.3.3 Summary

The energy consumption pattern for the mill is found to be 26% electricity and 74% saw dust fuel. The total electrical energy consumption of the factory is 631 kWh per tonne of paper produced. The electricity consumption for the paper machine seems to be satisfactory. Electrical energy saving can be achieved by reducing the energy demand for stock preparation by improving the technology and readjusting the illumination in the working areas. Saturated steam for process drying is produced at a rate of 3.6 tonnes per hour at a boiler efficiency of 79%. The steam consumption was found to be 2 tonnes per tonne of paper produced which is found to be satisfactory. The reduction in the moisture content in the saw dust will result in marginal saving of fuel to generate steam. The insulation of the thermal equipment and improvement of the distribution net work would reduce the thermal energy consumption.

5.4 Treatment Plant Audit

The process wastewater of the mill is conveyed to the treatment plant sump by a gravity canal and a bypass pump. The conveyance canals has not been cleaned for a long time and it contain large deposits of SS in the bottom of the drain. This tends to operate the by pass pump very frequently. The wastewater discharge measurements near the sump was carried out simultaneously for the gravity flow and bypass pump flow. The data for four days of flow measurement is presented in Appendix C Table C-33. The calibration of the bypass pump was conducted initially in order to find the pump flow (Appendix C Table C-32). The flow from the gravity canal was measured using a V-notch and the pump working time was measured using an hour meter. Two days of hourly flow measurement was carried out in order to find the hourly variation. Graphs in Appendix C Figs. C-1 and C-2 indicates that the hourly variation is not significant except for some peak values due to overflow of back water storage tanks.

In the results obtained, the average wastewater near the sump was found as 4027 m^3/day which was above the expected value. The reason for that was due to the unusual reuse water consumption as shown in Table A-34. It was decided to deduct this excess amount of reuse water consumption from the measured average. The calculated average value for the total wastewater was obtained as 3648 m^3/day. Having treated this wastewater for about 6.75 days, 1120 m^3/day is used back in the process and the remaining part is discharged to the Chao Phraya River. It was estimated that the amount of water evaporated in a day as 51 m^3, by assuming evaporation loss as 5 mm/day (METEOROLOGICAL STATION, 1996) and seepage in Bangkok soil as 0.003 mm/h (YINGJAJAVAL, 1993). The calculated quantity of wastewater to the river is found to be 2464 m^3/day. The total quantity of sludge generated in a day is found to be 2503 kg/day.

The cost analysis for wastewater treatment is presented in Table F-3 in Appendix F. The cost incurred for treatment of one cubic meter of wastewater is found to be 0.051 $/$m^3$. This excludes the labor and maintenance. The total cost of wastewater treatment is 0.06 $/$m^3$.

5.4.1 Waste Quality and Treatment Plant Efficiency

The wastewater stream contains discharges from the stock preparation and paper making processes. The storm water and the water used for general purposes are directly conveyed to the public canal.

Fig. 5.8 shows different discharge locations and the sampling points of the effluent treatment plant. Grab samples were obtained from all the sampling points and the resulting wastewater characteristics in terms of average temperature, pH, BOD, COD, TS and SS are shown in Table 5.21. Fig. 5.9 depicts the removal efficiency of each of the treatment plant unit operations.

Table 5.21 Effluent Quality Analysis for the Treatment Plant

Sampling Point	Sampling Location	Temp (^{0}C)	pH	SS (mg/L)	TS (mg/L)	DS (mg/L)	COD (mg/L)	BOD_5 (mg/L)
1	Sump	36	6.87	686	1551	879	770	82
2	Clarifier	36	6.79	30	860	826	210	63
3	Lagoon I	34	7.08	25	959	932	158	36
4	Lagoon II	32	7.30	10	850	835	99	23
5	Lagoon III	32	7.29	10	851	837	73	8

From the results in Table 5.21 it can be concluded that the COD component is mainly due to SS present in the wastewater. It can be noted that there is no dissolved solids removal from the above system.

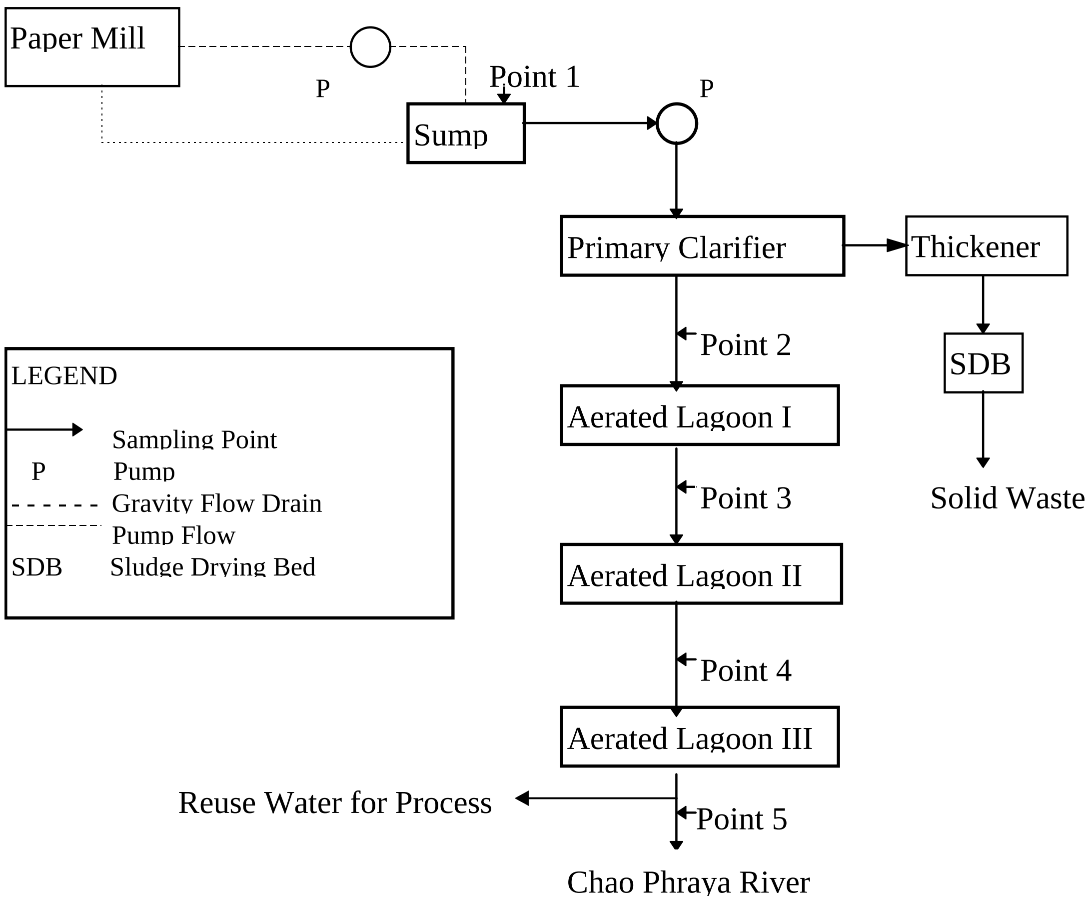

Fig. 5.8 Discharge Locations and Sampling Points at Effluent Treatment Plant

The analysis shows that the SS removal from the clarifier is within reasonable limits (<70%) yet the BOD removal is much less than the standard value of 40% (RAYTHEON ENGINEERS and CONSULTANTS INC., 1995). This contradicts the COD removal. It indicates that most of the SS are not biodegradable.

Alum is used as the coagulant in the clarifier. The line injection of alum is done at a predetermined constant rate of 50 mg/L. Jar test conducted at the AIT, environmental lab indicated that the optimum dosage is 70 mg/L. It is advisable to run a jar test experiment frequently in order to find the optimum alum dosage. This will not only improve the efficiency of the clarifier but also economic consumption of alum.

It was noted that in some occasions there is high amount of SS leaving through the weirs of the clarifier. This may be due to batch wise pumping of wastewater from the sump to the clarifier. It is advisable to pump the wastewater continuously at a rate of 152 m^3/h. In addition a baffle plate arrangement near the outlet would reduce floating objects leaving the weirs.

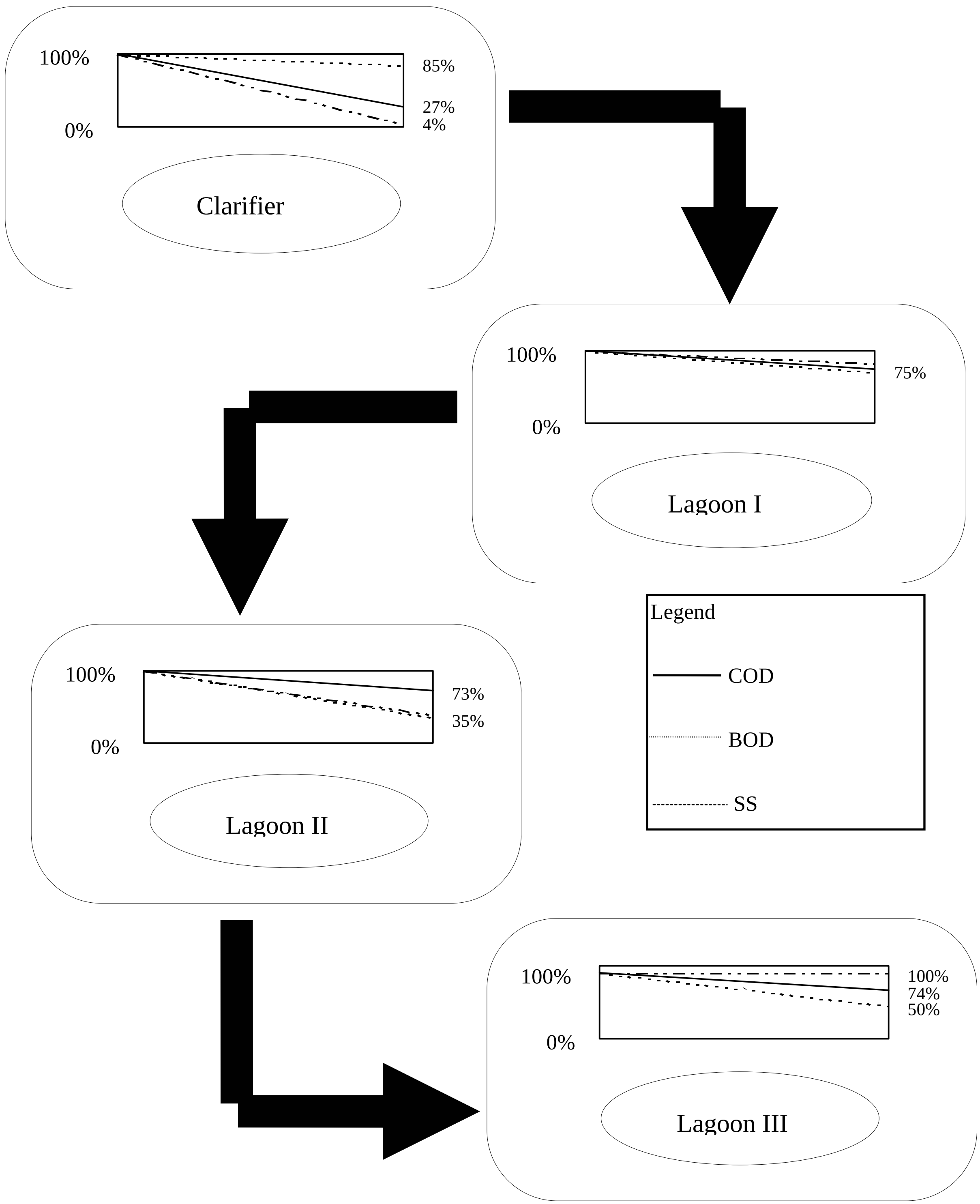

Fig. 5.9 Removal Efficiencies of Various Unit Operations

According to the design, oil and grease removal is done after the Lagoon III. In a proper design this should be one of the first operations to be carried out in order to over come the settling problems in the clarifier. It was also noticed that lot of sand particles are discharging from the stock preparation operation. These particles should be removed using a grit chamber other wise it will get contact with the clay particles and make a harder material and will create problems in removing using normal raking method. The Tables 5.22 and 5.23 compares the design criteria for clarifier and aerated lagoons with the actual data. It can be concluded that the existing units are within designed range. Manually clean bar screen installed near the sump is not effective since it disturbs the gravity flow of wastewater and hence the increase in water level in drains. This has to be replaced by a self cleaning continuous bar screen.

Table 5.22 Comparison of Design Criteria with the Actual Figures for the Clarifier

Parameter	Design Criteria (UNEP, 1981)	Existing Value
Diameter	50 m	9.9 m
Depth	4 - 5 m	3.4 m
Surface Loading	14 -24 m/day	23.5 m/day
Weir Loading	248 m^3/m.day	59 m^3/m.day
HRT	2 h	2.4 h

Table 5.23 Comparison of Design Criteria with the Actual Figures for Aerated lagoons

Parameter	Design Criteria (UNEP, 1981)	Existing Value
Water Temperature	25^0C	32^0C
HRT	5 - 10 days	6.75 days
Depth	4 m	3 m
Surface Loading	6 m/h	0.05 m/h
BOD Reduction	70 -90 %	90%
O_2 Consumption	1.6 g/g BOD_5 reduction	6.4 g/g BOD_5 reduction
Oxygenation Efficiency	1.6 kg O_2/kWh	Assume the same

It was found that the oxygen consumption is 4 times higher than the standard value. The Table 5.24 compares the available aeration capacity with the actual requirement for each of the lagoons. This indicates that an operation time of 6 h/day is sufficient to supply required oxygen. From the electricity measurements it seems that the aerators are working almost 24 hours per day. It is recommended to reduce the aeration capacity and work for 24 hours or to start aerators only during night.

Table 5.24 Comparison of Available Aeration Capacity with the Actual Requirement

Unit Operation	Available Capacity (kg/day)	Actual Requirement (kg/day)
Aerated Lagoon I	573	158
Aerated Lagoon II	429	76
Aerated Lagoon III	286	88

The thickened sludge from the thickener is designed to send to the sludge drying beds and then for land filling operations. It was noted that this sludge is pumped directly to the near by land. Hence most of the water drained from sludge will seep into the ground water layer causing high environmental pollution. The small quantity of solid waste generated from the production process is directly incinerated behind the factory.

Table 5.25 Comparison of Effluent Quality Standards with Thailand National Standards

Parameter	Teppattana Paper Mill	Standards in Thailand
BOD (mg/L)	8	20-60
COD (mg/L)	73	-
TS (mg/L)	851	-
SS (mg/L)	10	30
DS (mg/L)	837	2000
pH	7.29	5-9
T (^{0}C)	32	-

Source : ENVIRONMENTAL QUALITY STANDARDS DIVISION, THAILAND (1989)

The Table 5.25 presents the comparison between the actual effluent quality measurements with the required industrial effluent wastewater standards in Thailand. It can be concluded that effluent quality is well within the required limits.

5.4.2 Solid Balance

Table 5.26 displays the solid balance of the mill. The results indicate that SS and TS is within reasonable limits and the difference may be due to the accidental losses from the paper machine stuff box. The DS variation is about -5% from the value obtained for the sump. However DS in the sump is in agreement with unit operations following the sump. The ratio of SS and DS to TS, for the process is 45% and 55% respectively and for the sump is 44% and 56% respectively. This is acceptable due to the settling of suspended solids in the conveyance canal. This indicates that although there is a high variation of -5% for DS, the overall balance can assumed to be acceptable.

Table 5.26 Solid Balance

Location	Flow (m^3/day)	SS (kg/day)	DS (kg/day)	TS (kg/day)
PM I Drain I	1127	1120	1311	2435
PM I Drain II	217	6	87	93
SP I	77	388	104	492
PM II Drain I	611	243	514	757
PM II Drain II	442	139	301	441
SP II	46	298	60	358
PM III Drain I	350	68	154	214
PM III Drain II	776	226	512	734
SP III (Included in PM III Drain II)	87	-	-	-
Total	3646	2488	3043	5524
Sump	3648	2503	3207	5658
% Unaccounted	0%	-2%	-5%	-2%

It should be noted that although wastewater flow quantities are balancing, there is a difference of 164 m^3/day from the raw water consumption and wastewater generated as mentioned in Table 5.12. Part of this water could contribute to the sump water which is difficult to quantify.

The COD balance for the whole system is not possible because the COD generated from the stock preparation area was measured as filtered COD.

5.4.3 Summary

Gravity flow of wastewater is disturbed by the SS deposited in the conveyance canal hence it unnecessarily pump wastewater to the sump. The efficiency of the treatment plant was found to be functioning satisfactorily yet lack of a grit chamber with oil and grease removal is one of the major draw backs. It can be further improved by separating the waste volume coming from the stock preparation operation. This contains not only high SS but also high DS. The efficiency can be further improved by having continuous pumping of wastewater from the sump to the clarifier at a rate of 152 m^3/h. The designed aerators seems to be too much for the requirement resulting in high electricity loss. The sludge generated per day was found to be 2503 kg/day. The sludge coming out from the thickener should convey to the sludge drying beds without disposing to the ground. The possibility of this sludge to use as fuel for the boiler must be taken into consideration.

5.5 Cleaner Production Options

From the past experience it has found that cleaner production programs are not only feasible but also provide means of improving the image of the company in the eyes of work force as well as the general public. It will indirectly result in cost reduction for wastewater treatment and raw water consumption.

Table 5.27 describes the proposed cleaner production options for the three different sections, namely, stock preparation (SP), paper machine (PM) and utilities (U). Anticipated benefits , technical requirements and environmental aspects for each measure are also discussed here.

The implementation sequence is categorized among the following stages.

Stage I - Directly implementable

Stage II - Implementable with little analysis

Stage III - Implementable with further analysis

5.6 Proposals for Implementation

Some of the important cleaner production options and new proposals to reduce waste generation within the system are described below.

5.6.1 Cavity Air Floatation (CAF) Unit for PM II Wastewater

The main reasons to install a CAF unit for PM II are :

a) To reduce ground water consumption;

b) To reuse the fibre which is the most expensive out of the three products;

c) To reduce the pollution load to the treatment plant since it gives rise to high solid loading to the treatment plant;

The selected fibre recovery unit has a capacity of 30 m^3/h. Reuse of fibre recovered from the process has to be studied separately since it uses secondary fibre as raw material. This fiber is short compared to the accepted length and will reduce the strength properties and quality of paper. There is a possibility of using this for manufacturing of low grade paper such as toilet tissue. Therefore cost saving for fibre is not accounted in the economic analysis. The total pay back period for CAF is found to be 3 years as shown in Appendix F, Table F-2. This option is illustrated more clearly in Fig. 5.11.

5.6.2 Reuse of Vacuum Pump Seal Water

Vacuum pump seal water should be reused for paper machine shower water or for the same purpose after cooling by a suitable method. The estimated quantity of raw water reduction from this proposal is 337 m^3/day. To implement this there should be separate seal pits. The pressure inside the pit is below atmospheric and it requires pumps to extract water from the seal pit. Therefore further analysis is required before implementing this solution. The schematic diagram of the proposed system is shown in Fig. 5.10.

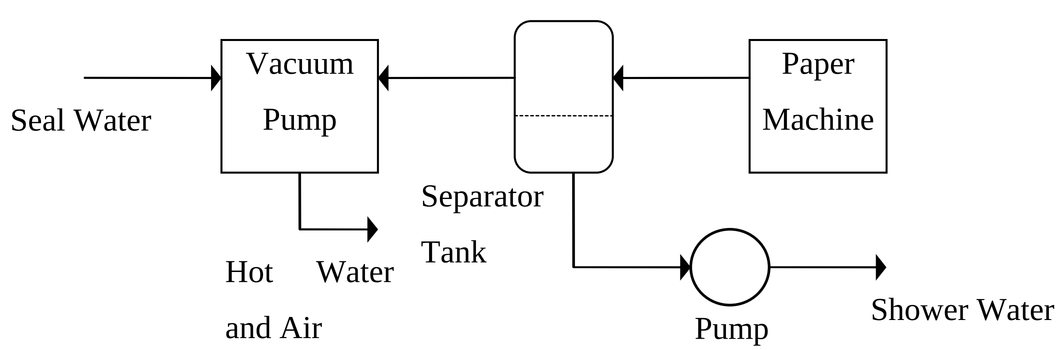

Fig. 5.10 Proposed Schematic Diagram for the Vacuum Pump Unit

5.6.3 Reuse of Lagoon III Water

Advanced treatment of Lagoon III water and reuse in the process is another possibility. This will not reduce the raw water consumption but it will pave the way for zero discharge and reduction in ground water consumption. The quality of raw water to the treatment plant is indicated in Table 5.21. It was calculated that the amount water available for treatment as 2625 m^3/day. Following are the details for the reuse water treatment plant.

a) Improve Primary Treatment : Installation of self cleaning bar screen at 30 mm spacing to prevent plastics and lager objects blocking the conveyance canal.

b) Improving Secondary Treatment :

- Chemical Preparation System : There is no proper chemical preparation system for coagulation and flocculation. Therefore two mixing tanks for chemical preparation should be constructed.

- Improve Injection System : In the existing method chemical is fed to the inlet of the clarifier using feed pumps. It is suggested to line inject the chemicals to the inlet of the clarifier water flow line. This will improve the mixing of coagulants with wastewater.

- Reconstruction of a Sump after the Clarifier : The existing sump after the clarifier has to be replaced by a new sump.

c) Installation of Advanced Water Treatment Plant

Fig. 5.11 shows the schematic diagram for the water treatment plant followed by a brief description of each unit.

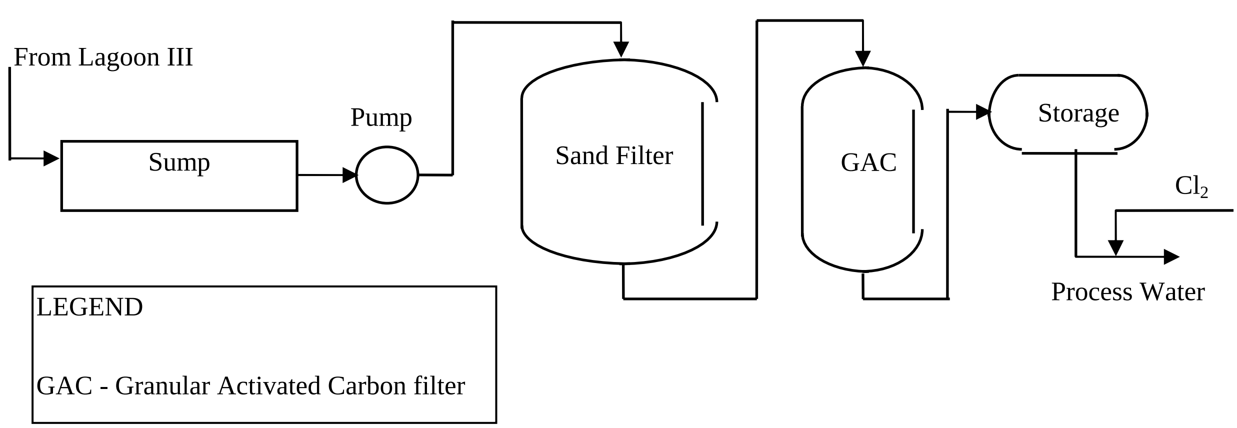

Fig 5.11 Schematic Diagram of the Water Treatment Plant

- Construction of storage water sump for Lagoon III water

- Granular filtration : To remove high influent suspended solids (if more than 20 mg/L) and to remove soluble organics associated with suspended solids. The design details are shown in Appendix G.

- Granular Activated Carbon (GAC) Filter : To remove low molecular weight polar organics by adsorption method. Under normal conditions, after treatment with carbon adsorption, the effluent COD is expected to have a range of 10-20 mg/L (METCALF and EDDY, 1991). The design details are shown in Appendix G.

- Chemical Oxidation : Chemical oxidation by chlorine to reduce bacterial and viral content in wastewater and to reduce concentrations of residual organics. The chlorine dosage would be of 2 mg/mg destroyed (METCALF and EDDY, 1991).

The economic analysis for the treatment plant is shown in Appendix F Table F-3. The pay back period for the treatment plant is 1.74 years which indicate that it is favorable for implementation. The design details given in Appendix G apply only to individually design filters. The cost data in the economic analysis is given for a complete unit of treatment capacity of 2500 m^3/day. The unit includes a granular filter, carbon adsorption filter, chemical oxidation system and pressure vessel for treated water storage.

5.6.4 Water and Wastewater Segregation

Isolating of strong wastes of stock preparation from the diluted effluent could substantially reduce the quality and accordingly the strength of wastewater for easy and economical treatment. Fig. 5.12 shows the effluent SS concentrations before and after segregation. From the proposed system expected reduction of solid loading to the clarifier is 42%. The reduction in raw water consumption from the proposed segregation system is found to be 28%.

5.7 Proposed Zero Discharge Targets

The proposed zero discharge targets are presented in Fig. 5.13. This will reduce the wastewater to the river by almost 100%. It is expected to reduce the ground water consumption by 83%. The main draw back of the system is that it does not remove the dissolved solids present in raw water. Following are some of the methods to overcome this problem:

a) Ion Exchange

b) Ultrafiltration

c) Reverse Osmosis

d) Electrodialysis

All these processes are very expensive due to the high operating pressure requirement and may not be economically attractive.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations for waste minimization strategies and waste reduction measures to achieve cleaner production at Teppattana Paper Mill can be developed as follows:

6.1 Paper Mill

Waste audit conducted to this factory included a raw water balance, wastewater balance, material balance and energy balance. The raw water consumption in the manufacturing process was found to be 89 m^3/tonne of paper which is about 7 times higher than the standard norms. The raw water used in the factory contained dissolved solids 4 times higher than the accepted values. The suspended solids leaving the manufacturing process is 59 kg/tonne of paper which is reasonable for a waste paper based mill. The electrical energy and steam energy consumption for the mill is 630 kWh/tonne of paper and 2.0 tonnes/tonne of paper respectively. These figures are within most of the available existing data yet it is possible to improve it further with few modifications. Some suggestions to improve its present status are described below.

6.1.1 Water and Wastewater Aspects

a) Installation of better nozzles in cleaning showers and provision of self closing valves for all raw water horses to prevent open horse losses.
b) Recovery of fibre from back water from paper machine drain and reuse the effluent for wire and felt cleaning through installation of micro filters. Expected reduction of ground water consumption from PM II is found to be 700 m^3/day and the pay back period for the investment is 3 years.
c) Vacuum pump seal water should be reused. This relatively hot water can be reused in shower spray in paper machine. This can also be used to the same purpose after cooling with suitable means. The expected reduction of raw water consumption is 337 m^3/day.
d) Isolating of strong wastes of stock preparation from the diluted effluent could substantially reduce the quality and accordingly the strength of wastewater for easy and economical treatment. Expected reduction of suspended solid loading to the primary clarifier is 33%.
e) Installation of water treatment unit for lagoon III water. The designed treatment capacity is 2500 m^3/day. The calculated pay back period for the investment is 1.74 years.

6.1.2 Process Modifications

a) Use of Poly Aluminum Silicate as sizing material instead of Alum.
b) Consistency indicator to reduce dependency on human judgment. It avoids the variation of grammage and reduces paper breakage.

c) It is noted that vacuum pump suction lines are piped directly from the suction point of the vacuum pump. The proper way of pipe up is to run suction line into a separate tank and then to a seal pit.
d) Replacement of most of the old and outdated equipment with modern automated equipment.

6.1.3 Energy Conservation

a) Technology upgradation by moderation and use of equipment with high productivity dryers.
b) Install Tri disc refiners to reduce the specific energy consumption at most 40% level.
c) Use of more effective press rolls to get as much dryness as possible (40% dryness) at paper web leaving the press section.
d) Avoid breakage and maintain runability of 95%.
e) It should be made compulsory from steam consumption section that 100% steam must be returned by them.
f) Insulation of all steam lines and evaporator bodies.
g) Recovery of flash steam.
h) Install power meters for each and every section and regular monitoring of power consumed.
i) Replacement or interchange of over size pumps and motors with most optimum size.

6.2 Effluent Treatment Plant

The audit conducted to the treatment plant indicated that it is functioning reasonably well at present and treated water is well within the industrial effluent standards in Thailand. One major draw back of the system is, there is no dissolved solid removal from the existing units. Sludge from the thickener should be properly treated in the existing sludge drying beds without discharging to the ground. Some of the possible improvements to the existing treatment plant are as follows:

a) Installation of a self cleaning bar screen
b) Construction of a grit chamber before the sump
c) Continuous pumping of wastewater from the sump to the clarifier
d) Improvement of chemical mixing and injection system
e) To conduct a jar test experiment regularly to find the optimum Alum dosage
f) Replace existing aerators with smaller capacity aerators to save electrical energy consumption
g) Treatment of wastewater from the staff housing before discharging to the public canal

6.3 Proposed Zero Discharge Plans

The proposed zero discharge plans and the anticipated reductions are tabulated in Table 6.1. It can be concluded that proposed plans could reduce the ground water consumption by 83% and effluent discharge to the river by almost 100%.

Table 6.1 Comparison of Present and Expected Data

Description	Present Data	Expected Results			
		CAF	Reuse of Seal Water	Reuse of Treated Water	Overall Impact
Ground Water (m^3/day)	2890	-700	-337	-1379	474
Reuse Water (m^3/day)	1121	-	-	2500	2500
Wastewater to Sump (m^3/day)	3648	-700	-337	-	2611
SS to Clarifier (kg/day)	2503	-275	-	-	2228
Effluent to River (m^3/day)	2460	-700	-337	-1379	44

Note : CAF - Cavity Air Flotation

6.4 Recommendations for Further Studies

a) Performing a complete economic analysis for the proposed cleaner production options; This will often become the key parameter for the management to accept or reject the waste minimization options.

b) Monitor and evaluate results after implementation of cleaner production options; The results obtained should be matched with the estimated/workedout during technical evaluation. Shortcomings should be highlighted and taken care of. The monitoring and review of the implemented measures should be presented so that to desire to minimize waste is encouraged.

c) Effects of high dissolved solids and hardness to the quality of paper; The dissolved solids and in raw water is comparatively high compared to the standard values and it will increase further with the implementation of the proposed suggestions. The effect of this to the quality of paper should be studied separately.

d) Chemical scanning for Sown-glue Honor-650, Deformer, Modified Starch, Wax, Bleaching Reagent and Antiseptic for possible toxic substances since the manufacturers have not specified the chemicals present in them. This must also be extended for wastewater since it uses waste paper as raw material.

e) To study the suitability of dried sludge from the sludge drying beds as fuel to the boiler; There is a possibility of using this sludge as fuel to the boiler after grinding it with suitable means and mixing with a known proportion of saw dust.

f) To study the suitability of recovered fibre to use in the production process; The fibre recovered from the waste streams may be small compared to the required length and it may affect the physical properties of produced paper.

g) To conduct a detail energy audit at least for electrical section since it utilizes 80% of the total energy cost.

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APPENDIX A
GENERAL INFORMATION

Table A-1 Availability of Data

No	Particulars	Yes/ No	Source and Access	Remarks on Usefulness or Upgradation
1.	Factory layout	Yes	Maintenance Office on request	Useful
2.	Production details	Yes	Production Department	Useful
3.	List of major chemicals and raw materials along with unit costs.	Yes	Production Department	Very useful
4.	Water consumption			
	- Overall	Yes	Environment Section	Very useful
	- Individual department	No		
5.	Energy consumption			
	- Overall	Yes	Production Department	The figures for individual departments are obtained from 1990 data.
	- Individual department	Yes		
6.	Process flow diagram	Yes	Production Department	Very useful
7.	Material balance	No	-	Only input and output data was available.
8.	Energy balance	No	-	-
9.	Quality results	Yes	Quality Control Section on request.	Limited useful
10.	End of pipe control facility	Yes	Environment Section	Useful
11.	Cost data for economic analysis	Yes	Production Department	Very useful
12.	Proposed projects	Yes	Production Department	Very useful

APPENDIX B
PARAMETERS MEASURED IN THE WASTE AUDIT

Table B-1 Parameters Measured in the Waste Audit

Parameter Measured	Unit	Method/Equipment/Place
pH	-	pH Meter/Knick > Portamess 751 Calimatic
SS	mg/L	Standard Method
TS	mg/L	Standard Method
COD	mg/L	Standard Method
Temperature	^0C	Thermometer
Optumum Alum Dosage	-	Jar Test/EE Lab
Time of Operation	h	Hour Meter/Grasslin FWZ 220V~50Hz/Physical Plant
Raw Water Measurement	m^3	Flow Meter/EE Lab
	m^3/s	Potable type Ultrasonic Flow Meter Type FLB/Hydraulic Lab, AIT
Reuse Water Measurement	m^3	Flow Meter/Teppattana Paper Mill
Wastewater Flow Measurement	m^3/s	PMI Drain I : $Q = 4.79X10^{-6} H^{2.556}$
	m^3/s	PMII Drain I : $Q = 8.98X10^{-6} H^{2.427}$
	m^3/s	PMII Drain II : $Q = 9.07X10^{-6} H^{2.400}$
	m^3/s	PMIII Drain I : $Q = 1.13X10^{-5} H^{2.439}$
	m^3/s	PMIII Drain II : $Q = 8.98X10^{-6} H^{2.427}$
	m^3/s	Sump : $Q = 7.17X10^{-6} H^{2.434}$
Water Level Measurement	mm	Floater/EE Lab
Consistency Measurement	-	Factory records

Note : H = Height in cm

Table C-1 Monthly Raw Water Consumption of the Mill

Month	G/W (m^3)	Reuse water	
		PM I (m^3)	PM II (m^3)
Feb., 95	82627	23507	6454
Mar	80990	21157	-
April	94958	-	-
May	89850	-	-
June	79946	26496	3271
July	79330	25207	10764
Aug.	84998	24160	4633
Sept.	94685	15967	1778
Oct.	87130	30081	1387
Nov.	89238	26074	3277
Dec.	75161	26953	4326
Jan, 96	-	32242	9030
Feb.	-	31317	4614
Mar	-	38892	12776
April	-	29260	7266

Average Ground Water (G/W) Consumption = 84,264 m^3/month (2809 m^3/day)
Reuse Water Consumption PM I = 27529 m^3/month (918 m^3/day)
Reuse Water Consumption PM III = 4031 m^3/month (134 m^3/day)

Table C-2 Daily Ground Water Consumption of the Factory

Date	Consumption (m^3)
26/01/96	2732
27/01/96	2892
28/01/96	2869
29/01/96	2972
30/01/96	2948
31/01/96	2851
01/02/96	2868
02/02/96	2975
03/02/96	2947
04/02/96	2842
05/02/96	2893
06/02/96	2887

Average Ground Water Consumption for the Factory = 2890 m^3/day.

Table C-3 Reuse Water Consumption of the Factory

PM I		PM III	
Date	Volume (m^3)	Date	Volume (m^3)
02/02/96	1092	16/02/96	144
03/02/96	1059	17/02/96	137
04/02/96	964	18/02/96	137
05/02/96	956	19/02/96	144
06/02/96	969	20/02/96	132
07/02/96	970	21/02/96	139
08/02/98	934	22/02/96	143
09/02/96	900	23/02/96	-
10/02/96	993	24/02/96	138
		25/02/96	138

Average Reuse Water Consumption for PM I = 982 m^3/day.

Average Reuse Water Consumption for PM III = 139 m^3/day.

Table C-4 Ground Water Consumption for the Three Paper Machines

Measured on 29/02/96

Time	Flow Rate (m^3/h)
9.55	90.8
10.00	94.7
10.05	91.7
10.10	99.2
10.15	89.2
10.20	94.9
10.25	95.9
10.30	91.1
10.35	92.7
10.40	93.8
10.45	89.2
10.50	87.7
10.55	94.7
11.00	94.0
11.05	88.5
11.10	89.7
11.15	92.9
11.20	94.0
11.25	95.8
11.30	92.7
11.35	89.1
11.40	96.5
11.45	97.5
11.50	96.1
11.55	96.2
12.00	89.6
12.05	95.6
12.10	95.3
12.15	85.3
12.45	97.1
12.50	98.0
12.55	95.9
13.00	95.8
13.05	91.5

Average Flow = 93.3 m^3/h

Table C-4 Contd.
Measured on 28/03/96

Time	Flow Rate (m^3/h)
12.45	96.7
12.50	93.8
12.55	95.9
1.00	90.0
1.05	96.5
1.10	96.7
1.15	94.1
1.20	97.3
1.25	91.6
3.35	97.5
3.40	93.4
3.45	91.7
3.50	93.3
3.55	93.9
4.00	96.8
4.05	94.9
4.10	97.8
4.15	97.1
4.20	91.5
4.25	87.6
4.30	95.0

Average Flow = 94.4 m^3/h

Average Ground Water Consumption for the three Paper Machines = 93.9 m^3/h (2254 m^3/day).

Table C-5 Ground Water Consumption for PM I

Time	Flow Rate (m^3/h)
9.55	6.17
10.00	5.26
10.05	5.35

10.10	5.41
10.15	4.98
10.20	4.89
10.25	4.94
10.30	5.30
10.35	5.25
10.45	5.70
10.50	5.31
10.55	5.33
11.00	5.35
11.05	5.42
11.10	5.25
11.15	5.24
11.20	5.32
11.25	5.53
11.30	5.44
11.35	5.33
11.40	5.10
11.45	5.20
11.50	5.16
11.55	5.22
12.00	5.37

Measured Average Ground Water Consumption for PM I = 5.3 m^3/h
Estimated Ground Water Consumption in two showers PM I = 5.2 m^3/h (Ref. Table C12)

Total Ground Water Consumption for PM I = 10.3m^3/h

Average Ground Water Flow = 37.4 m^3/h

Table C-6 Ground Water Consumption for PM II

Measured on 27/02/96

Time	Flow Rate (m^3/h)
10.35	39.09
10.45	35.65

Table C-6 Contd.

Measured on 01/04/96

Time	Flow Rate (m^3/h)
10.50	37.1
10.55	35.2
11.00	37.7
11.05	41.1
11.10	40.5
11.15	43.3
11.20	42.2

11.25	40.7
11.30	40.6
11.35	41.0
11.40	39.4
11.45	41.0
11.50	41.2
11.55	40.1
12.00	36.1
12.05	38.0
12.10	37.2
12.15	36.0
12.35	37.5
12.40	38.0
12.45	37.2
12.50	38.0
12.55	38.0
13.00	38.0
13.05	32.7
13.10	33.6
13.15	38.9
13.55	36.7
14.00	36.8
14.05	36.4
14.10	37.2
14.15	35.2
14.20	31.8
14.25	34.2
14.30	34.6
14.35	33.2
14.40	35.1
14.50	33.5
15.05	38.1
15.10	38.2
15.15	36.8
15.20	36.7
15.25	39.0
15.30	36.5
15.35	37.8
15.40	36.8
15.45	34.9
15.50	36.7
15.55	35.2
16.00	37.8
16.05	36.1
16.10	36.2
16.15	37.8
16.20	36.7
16.25	37.0
16.40	37.6

Average Flow = 37.3 m^3/h

Total Average Flow of Water for PM II = 37 m^3/h.

Table C-7 Ground Water Consumption for SP I

Date	Volume (m^3)
09/03/96	62.8
12/03/96	57.8
16/03/96	65.3

Average Flow of Water = 70 m^3/day.

Table C-8 Ground Water Consumption for SP II

Date	Volume (m^3)
09/03/96	66.3
12/03/96	78.4
16/03/96	69.2
20/03/96	56.7
21/03/96	64.3
22/03/96	71.1
04/04/96	53.5

Average Flow = 66 m^3/day.
Ground Water Consumption for Virgin Pulp = 134 m^3/day.

Table C-9 Ground Water Consumption for SP III

Date	Volume (m^3)
09/03/96	83.0
12/03/96	88.3
16/03/96	87.5
20/03/96	87.0
21/03/96	93.3
22/03/96	79.0
26/03/96	87.7

Average Flow = 87 m^3/day.

Table C-10 Cooling Water Consumption for the Large Vacuum Pump

Date	Volume (m^3)
09/03/96	71.4
12/03/96	88.9
16/03/96	83.0
22/03/96	72.3

26/03/96	55.2
27/03/96	54.8
28/03/96	46.1
02/04/96	52.7
03/03/96	52.1

Average Flow = 64 m^3/day

Table C-11 Cooling Water Consumption for the Small Vacuum Pump

Date	Volume (m^3)
09/03/96	30.6
16/03/96	31.9
20/03/96	30.3
21/03/96	29.0
22/03/96	24.8
26/03/96	22.3

Average Flow = 28 m^3/day

Table C-12 Shower Water Consumption for One Shower in SP II

Date	Volume (m^3)
09/03/96	46.27
12/03/96	50.23
16/03/96	40.37
21/03/96	40.18

Time of operation = 17.06 h/day
Average water flow = 45 m^3
Average flow rate = 2.6 m^3/h

Table C-13 Ground Water Fed to the Softener

Date	Volume (m^3)
04/04/96	25.88
05/04/96	23.20
06/04/96	23.80
07/04/96	22.00
08/04/96	21.00

Average water flow = 24 m^3/day

Table C-14 Ground Water Consumption for Staff Housing Behind the Factory

Date	Volume (m^3)
02/04/96	102.1
03/04/96	97.4
04/04/96	85.5
05/04/96	90.2
06/04/96	115.2
07/04/96	103.1
08/04/96	101.2
09/04/96	95.7
10/04/96	98.0
11/04/96	93.6

Average water flow = 98 m^3/day

Table C-15 Ground Water for Staff Housing Adjoining the Factory

Month	Volume (m^3)
February	52
March	58
April	69

Average water flow = 2 m^3/day

Table C-16 Consistency Measurements for Duplex Board (PM I)

Consistency Measurements for Line D

Unit Process	19/04/96	20/04/96	23/04/96	Average
Hydra Pulper	5.57	3.83	4.64	4.68
Jonson Screen	0.87	0.31	0.85	0.68
Riffler	2.91	2.78	2.15	2.61
Fine Screen	1.34	1.80	2.41	1.85
Centricleaner	2.57	3.10	3.31	2.99
Decker	3.34	3.69	2.77	3.50
Stuff Box	0.48	0.59	0.72	0.60

Consistency Measurements for Line BC

Unit Process	17/04/96	19/04/96	20/04/96	Average
Hydra Pulper	4.00	3.69	4.03	3.91
Jonson Screen	1.45	0.70	0.15	0.77
Riffler	2.91	2.70	2.85	2.82
Fine Screen	2.01	1.55	1.85	1.81
Centricleaner	2.27	1.38	2.95	2.20
Decker	3.13	3.25	3.65	3.34
Stuff Box	0.42	0.79	0.59	0.60

Consistency Measurements for Line A

Unit Process	17/04/96	19/04/96	20/04/96	Average
Hydra Pulper	3.53	3.12	2.88	3.07
Riffler	1.05	1.18	0.85	1.03
Centricleaner	0.99	1.04	0.69	0.91
Decker	3.01	3.08	3.24	3.14
Stuff Box	0.32	0.32	0.52	0.39

Table C-17 Consistency Measurements for Glass Interleaving Paper (PM II)

Unit Process	30/04/96	02/04/96	03/04/96	Average
Hydra Pulper	2.10	2.60	2.50	2.40
SP 20206	1.89	1.85	1.69	1.81
Jonson Screen	0.82	0.92	0.84	0.86
Centricleaner	0.85	0.92	0.96	0.91
Decker	2.75	2.86	1.74	2.45
SP 20201	2.88	2.65	2.06	2.53
Stuff Box	0.37	0.38	0.39	0.38

Table C-18 Consistency Measurements for Printing and Writing Paper (PM II)

Unit Process	20/06/96	21/06/96	22/06/96	Average
Hydra Pulper (VP)	3.78	3.15	3.69	3.54
Hydra Pulper (WP)	3.62	2.96	3.38	3.29
SP 20206	3.09	2.80	3.01	2.97
Jonson Screen	1.40	1.06	1.29	1.25
Centricleaner	1.54	1.29	1.28	1.37
Decker	3.46	3.57	3.64	3.56
SP 21101	3.65	3.44	3.46	3.52
SP 20201	3.33	3.46	3.54	3.44
Stuff Box	0.46	0.53	0.50	0.50

Note: VP = Virgin Pulp, WP = Waste Paper

Table C-19 Consistency Measurements for Glass Interleaving Paper (PM III)

Unit Process	23/04/96	24/04/96	25/04/96	Average
Hydra Pulper	3.63	4.61	3.63	3.96
SP 30206	3.45	2.85	2.66	3.00
3F Screen	2.38	2.87	2.30	2.52
Centricleaner	1.59	2.05	1.61	1.75
Decker	2.47	2.48	2.74	2.57
SP 30201	2.52	2.68	2.67	2.62
Stuff Box	0.68	0.58	0.62	0.63

Table C-20 Moisture Content of Paper

Date	Duplex Board (PM I)			P&W (PM II)			GI (PM III)		
	Reel	Press	Forming	Reel	Press	Forming	Reel	Press	Forming
30/04/96	4.19	60.2	85.1	3.8	69.0	81.7	4.8	79.7	92.3
08/05/96	1.94	62.5	81.2	2.7	74.5	83.2	3.2	74.9	92.9
Average	3.1	61.3	83.1	3.3	71.8	82.4	4.0	77.3	92.6

Table C-20 Contd. Moisture Content of Printing and Writing Paper (PM II)

Date	Reel	Press	Forming
20/06/96	3.5	54.5	80.4
21/06/96	4.5	55.0	79.1
Average	4.0	54.8	79.8

Table C-21 Time of Operation for SP I

Date	Time (h)	Average/day
20/03/96	12.42	12.42
21/03/96	12.45	12.45
22/03/96-25/03/96	36.46	11.56
26/03/96	13.20	13.20

Average time of Stock Preparation for SP I = 12.42 h

Table C-22 Time of Operation for SP II

Date	Time (h)	Average/day
28/03/96	16.89	16.89
29/03/96-01/03/96	61.31	20.43
02/03/96	20.43	20.43

Average time of Stock Preparation for SP II = 19.73 h

Table C-23 Time of Operation for SP III

Date	Time (h)
20/04/96	10.18
21/04/96	11.25
22/04/96	10.63
24/04/96	12.38

Average time of Stock Preparation for SP III = 11.11 h

Table C-24 Wastewater Discharged from SP I Measured on 26/03/96

Line BC			Line A			Total		
Time (s)	Qty (L)	Flow Rate (m^3/h)	Time (s)	Qty (L)	Flow Rate (m^3/h)	Time (s)	Qty (L)	Flow Rate (m^3/h)
8.30	2.25	0.98	7.95	2.40	1.09	4.62	8.25	6.42
7.81	2.05	0.94	7.64	2.30	1.08	6.09	9.20	5.43
8.53	2.25	0.95	7.09	2.10	1.07	4.74	8.85	6.72
8.16	2.20	0.97	7.46	2.25	1.07	4.24	9.15	6.29
8.24	2.20	0.96	6.67	2.20	1.08			
			6.84	2.20	1.05			
			8.43	2.50	1.07			

Total Average Flow from SP I = 6.22 m^3/h
Daily Average Flow from SP I = 77 m^3/day
Average Flow From Line BC = 0.96 m^3/h
Daily Average Flow from Line BC = 11.92 m^3/day

Average Flow from Line A = 1.08 m^3/h
Daily Average Flow from Line BC = 13.48 m^3/day

Calculated Flow from Line D = 4.18 m^3/h
Calculated Daily Average Flow from Line D = 51.91 m^3/day

Table C-25 Wastewater Discharged from SP II Measured on 26/03/96

Time (s)	Quantity (m^3)	Flow Rate (m^3/h)
5.83	2.55	1.57
5.51	2.50	1.63
5.29	2.35	1.60
5.74	2.50	1.57
5.79	2.50	1.55
6.13	2.75	1.62

Total Average Flow from SP II = 1.59 m^3/h
Apart from the above there was a flow of 0.39 m^3/h (8 m^3/day) from the first centricleaner where the pollution was neglected.

Daily Average Flow from SP II = 46 m^3/day

Table C-26 Wastewater Discharged from SP III Measured on 26/03/96

Time (s)	Volume (m^3)	Flow Rate (m^3/h)
12.55	8600	0.69
13.55	10,100	0.75
13.16	9550	0.73
11.63	9000	0.77

Total Average Flow from SP III = 2.78 m^3/h
Daily Average Flow from SP III = 31 m^3/day

Table C-27 Flow Measurement of Wastewater Discharged from PM I Drain II

Suction Pump No 1

Time (S)	Volume (L)	Flow Rate (m^3/h)
17.19	11.70	2.45
25.39	12.75	1.81
17.91	10.80	2.17
19.65	11.00	2.02
18.27	10.65	2.10

Average flow = 2.11 m^3/h

Suction Pump No 2

Time (S)	Volume (L)	Flow Rate (m^3/h)
7.51	9.80	4.70
8.06	11.40	5.09
7.69	9.20	4.31
8.53	12.10	5.11

Average flow = 4.80 m^3/h

Suction Pump No 3

Time (S)	Volume (L)	Flow Rate (m^3/h)
17.19	10.00	2.09
15.74	9.90	2.26
17.02	11.00	2.33
19.23	10.50	1.97
18.53	10.50	2.04

Average flow = 2.14 m^3/h

Total flow from PM I drain II = 9.05 m^3/h (217 m^3/day)

Table C-28 Flow Measurement of Wastewater Discharged from PM I Drain I

Description	Average Height (cm)	Flow (m^3/day)
Drain I	22.6	1197

Note : Continuous water level measurements for drain I was taken on 09/05/96 for 6 hours.

Table C-29 Flow Measurement of Wastewater Discharged from PM II

Description	Average Height (cm)	Flow (m^3/day)
Drain I	14.5	511.2
Drain II	14.0	441.8

Note : Continuous water level measurements for drain I was taken on 27/03/96 and drain II was taken on 21/03/96 and 26/03/96.
Total wastewater flow from PM II = 953 m^3/day.

Table C-30 Flow Measurement of Wastewater Discharged from PM III

Description	Average Height (cm)	Flow (m^3/day)
Total Flow	18.0	1126
Drain I	7.8	350

Note : Continuous water level measurements was measured on 19/03/96 and 20/03/96.
Total flow includes the wastewater from SP III.

Calculated quantity of wastewater from Drain II = 776 m^3/day

Table C-31 Solid Waste Generated from Stock Preparation

Process	Amount (kg/day)
Stock Preparation I	360
Stock Preparation II (P&W)	59
Stock Preparation II (GI)	12
Stock Preparation III	26

Table C-32 Calibration of Wastewater Discharge Pump

Set	Time Duration (s)	Average Ht. (cm)	Flow From the Weir		Total Flow (m^3)	Flow from the Pump (m^3)	Pump Flow Rate (m^3/h)
			Step Flow	Weir Flow			
1	0 -90	29.9	2.519	4.98	14.58	9.6	192
	90 -180	29.6	2.458				
2	0 -90	30.6	2.665	5.18	15.53	10.53	207
	90 -180	29.9	2.519				
3	0 -90	30.2	2.581	5.07	15.53	10.46	209
	90 -180	29.75	2.489				
4	0 -90	30.6	2.665	5.16	16.45	11.29	225
	90 -180	29.8	2.479				

Note : Average flow was obtained by taking measurements at every 30 s intervals.
Average pumping rate = 208.5 m^3/h

Table C-33 Flow Measurement of Wastewater Discharged near the Sump

Date	Weir		Pump			Total Flow (m^3/day)
	Av. Ht. (cm)	Flow (m^3)	Initial Reading (h)	Final Reading (h)	Flow (m^3)	
04/04/96	30.1	2363	162.51	167.42	940	3300
06/04/96	31.5	2746	167.48	175.05	1578	4324
09/04/96	30.4	2552	197.56	204.11	1366	3886
10/04/96	29.2	2867	204.11	212.42	1733	4599

Note : Average flow through the weir was obtained using continuous water level measurements for 24 hours.

Average flow of wastewater near the sump = 4027 m^3/day.

Table C-34 Reuse Water Consumption for Particular Days of Sump Flow Measurement

Date	Volume (m^3)
04/04/96	1554
06/04/96	1080
09/04/96	1675
10/04/96	1694

Average Water Consumption = 1500 m^3/day

Table C-35 Energy Consumption for the Year 1995

Month	Electricity (MWh)	Saw Dust (m^3)	Oil (L)	Boiler Feed Water (m^3)
January	778.92	1989.43	17500	2697
February	701.44	1833.10	1500	2427
March	814.36	2119.46	800	3035
April	689.20	1753.97	-	2246
May	828.88	2273.94	700	2886
June	834.30	2356.32	3900	2814
July	867.56	1947.83	33,300	2556
August	869.08	2438.43	500	2876
September	833.94	2410.31	-	2897
October	719.58	2171.39	8400	1989
November	834.14	2210.96	25,200	2704
December	723.46	1889.43	-	1740
Average	791.24	2116.21		2572

Table C-36 Daily Average Electricity Load at Different Sections (SRIPADIT, 1990)

Section	Load (kW)
SP I	320.8
SP II	92.1
SP III	137.6
PM I	233.4
PM II	100.0
PM III	87.9
1	113.4
2	20.6
3	16.8
4	26.4
Total	1149

SP I = Stock Preparation for Paper and Board
SP II = Stock Preparation for Printing and Writing Paper
SP III = Stock Preparation for Glass Interleaving Paper
PM I = Paper Machine for Paper and Board
PM II = Paper Machine for Printing and Writing Paper
PM III = Paper Machine for Glass Interleaving Paper
1. Ground water pumping and wastewater treatment
2. Lighting at boiler room and worker quarters
3. Other lighting
4. Boiler room

Table C-37 Waste Stream Analysis of Duplex Board (PM I)

Date	Drain I						Drain II					
	Temp ^{0}C	pH	SS mg/L	TS mg/L	DS mg/L	COD mg/L	Temp ^{0}C	pH	SS mg/L	TS mg/L	DS mg/L	COD mg/L
07.02.96	36.0	6.99	1140	2320	1180	1384	-	-	-	-	-	-
12.02.96	34.0	6.48	1267	2045	778	944	34.0	7.38	100	-	-	0
14.02.96	-	-	-	-	-	-	35.0	7.42	<10	381	371	83
15.02.96	35.0	6.72	1020	2048	1028	1217	36.0	7.40	79	750	671	122
09.03.96	36.0	6.57	1000	2100	1100	1217	37.0	7.25	<10	355	345	72
11.03.96	35.5	6.98	860	1610	750	1034	38.0	7.37	59	550	491	30
12.03.96	35.0	6.99	889	2150	1261	1255	39.0	7.57	20	244	224	48
16.03.96	34.0	6.76	1332	2489	1157	1509	38.5.	7.25	55	622	567	58
21.03.96	34.0	6.5	1054	2304	1250	1694	-	-	-	-	-	-

Table C-38 Waste Stream Analysis of Printing and Writing Paper (PM II)

Date	Drain I						Drain II					
	Temp ^{0}C	pH	SS mg/L	TS mg/L	DS mg/L	COD mg/L	Temp ^{0}C	pH	SS mg/L	TS mg/L	DS mg/L	COD mg/L
12.03.96	38.0	6.95	357	1238	881	399	38.0	6.92	235	810	575	281
14.03.96	38.5	7.21	480	1130	650	443	38.5	7.29	514	1190	676	399
15.03.96	37.0	6.75	451	1091	640	436	37.5	7.14	473	930	457	342
16.03.96	38.0	7.00	420	1182	762	444	38.0	7.17	300	773	473	225
21.03.96	38.5	6.88	360	1478	1118	367	38.0	7.05	216	1370	1154	254
22.03.96	38.0	6.87	321	1317	996	296	38.0	7.25	236	1000	764	169
25.03.96	39.0	7.14	745	1792	1047	626	39.0	7.50	229	905	676	202

Table C-39 Waste Stream Analysis of Glass Interleaving Paper (PM II)

Date	Drain I						Drain II					
	Temp ^{0}C	pH	SS mg/L	TS mg/L	DS mg/L	COD mg/L	Temp ^{0}C	pH	SS mg/L	TS mg/L	DS mg/L	COD mg/L
07.02.96	38.0	4.06	480	1160	680	488	-	-	-	-	-	-
12.02.96	36.0	4.25	781	1773	992	661	33.9	6.52	667	-	-	535
13.02.96	34.0	4.28	379	1130	751	283	33.0	6.90	200	667	467	0
14.02.96	37.5	6.33	388	818	430	393	34.0	6.98	60	650	590	157
15.02.96	38.0	5.12	460	1160	700	220	36.0	7.18	<10	440	430	173
09.03.96	39.0	6.18	311	773	462	405	32.0	7.15	80	439	359	117
11.03.96	39.5	5.66	396	1250	850	473	37.0	7.21	200	480	280	107

Table C-40 Waste Stream Analysis of Glass Interleaving Paper (PM III)

Date	Drain I						Drain II					
	Temp ^{0}C	pH	SS mg/L	TS mg/L	DS mg/L	COD mg/L	Temp ^{0}C	pH	SS mg/L	TS mg/L	DS mg/L	COD mg/L
12.02.96	31.0	6.70	209	1292	1083	31	34.0	6.53	267	-	-	378
13.02.96	33.0	6.74	192	731	539	197	35.0	6.80	423	920	497	472
14.02.96	35.0	6.91	216	636	420	173	37.0	6.68	160	1000	840	220
15.02.96	35.0	6.93	175	698	523	630	37.0	5.78	510	1208	698	755
09.03.96	37.0	6.72	172	450	278	322	39.0	7.20	94	700	606	158
11.03.96	33.0	6.68	98	537	439	192	34.0	6.32	33	900	867	369

Table C-41 Waste Stream Analysis for Duplex Board (SP I)

Date	Temp (^{0}C)	pH	SS (mg/L)	TS (mg/L)	DS (mg/L)	COD (F) (mg/L)
14.02.96	31.0	7.07	5120	6480	1360	362
15.02.96	33.0	6.95	4346	5767	1421	330
09.03.96	35.0	7.00	6190	7667	1477	473
11.03.96	36.0	6.96	4484	5659	1175	517

Table C-42 Waste Stream Analysis for Printing and Writing Paper (SP II)

Date	Temp (^{0}C)	pH	SS (mg/L)	TS (mg/L)	DS (mg/L)	COD (F) (mg/L)
14.03.96	40.5	7.07	9594	10,688	1094	380
16.03.96	40.0	6.80	44,150	56,167	12,017	305
21.03.96	40.5	6.91	4775	6714	1939	300
22.03.96	41.5	6.79	9195	10,864	1669	247
25.03.96	41.0	7.05	35,149	38,667	3518	-

Table C-43 Waste Stream Analysis for Glass Interleaving Paper (SP II)

Date	Temp (^{0}C)	pH	SS (mg/L)	TS (mg/L)	DS (mg/L)	COD (F) (mg/L)
12.02.96	-	3.59	4219	5941	1722	-
13.02.96	36.0	4.03	3925	5569	1644	20
14.02.96	36.0	4.05	6269	7364	1095	55
15.02.96	39.0	4.00	4527	6345	1818	79
09.03.96	39.5	4.17	5220	6864	1644	113
11.03.96	42.0	5.80	3868	5350	1482	111

Table C-44 Waste Stream Analysis for Glass Interleaving Paper (SP III)

Date	Temp (^{0}C)	pH	SS (mg/L)	TS (mg/L)	DS (mg/L)	COD (F) (mg/L)
12.02.96	33.0	4.61	1969	-	-	-
13.02.96	31.0	5.96	1981	2680	699	39
15.02.96	34.0	4.19	1750	2857	1107	153
11.03.96	37.0	3.94	1286	2150	864	155
12.03.96	38.0	5.36	1250	1909	659	89

Characteristics of Wastewater Discharged from the Effluent Treatment Plant

Table C-45 Characteristics of Wastewater in the Sump

Date	Temp (^{0}C)	pH	SS (mg/L)	TS (mg/L)	DS (mg/L)	COD (mg/L)
12.03.96	35.5	6.72	1786	2292	506	1514
14.03.96	35.5	6.90	603	1250	647	901
15.03.96	36.0	6.88	667	1440	773	727
21.03.96	36.5	6.58	722	1682	960	791
22.03.96	36.5	6.97	750	1885	1135	706
25.03.96	37.0	7.18	529	1500	971	723

Table C-46 Characteristics of Wastewater from the Clarifier

Date	Temp (^{0}C)	pH	SS (mg/L)	TS (mg/L)	DS (mg/L)	COD (mg/L)
12.03.96	35.0	6.75	20	1106	1086	207
14.03.96	35.5	6.90	78	905	827	233
15.03.96	36.0	6.62	20	762	742	189
21.03.96	36.0	6.63	20	583	563	212
22.03.96	36.0	6.83	20	917	897	205
25.03.96	36	6.98	20	857	837	216

Table C-47 Characteristics of Wastewater from the Aerated Lagoon I

Date	Temp (^{0}C)	pH	SS (mg/L)	TS (mg/L)	DS (mg/L)	COD (mg/L)
12.03.96	33.0	6.97	<10	1021	1011	148
14.03.96	33.5	7.25	39	863	824	155
15.03.96	33.0	7.02	60	1000	940	175
21.03.96	34.0	6.85	20	1091	1071	148
22.03.96	33.5	7.14	20	863	840	159
25.03.96	34.0	7.27	<10	913	903	160

Table C-48 Characteristics of Wastewater from the Aerated Lagoon II

Date	Temp (^{0}C)	pH	SS (mg/L)	TS (mg/L)	DS (mg/L)	COD (mg/L)
12.03.96	32.0	7.24	<10	634	624	89
14.03.96	32.0	7.52	<10	720	710	85
15.03.96	32.0	7.29	20	952	932	102
21.03.96	32.0	7.03	<10	857	847	95
22.03.96	32.5	7.33	<10	1048	1038	102
25.03.96	33.0	7.36	20	870	850	118

Table C-49 Characteristics of Wastewater from the Aerated Lagoon III

Date	Temp (^{0}C)	pH	SS (mg/L)	TS (mg/L)	DS (mg/L)	COD (mg/L)
12.03.96	31.0	7.10	<10	439	429	59
14.03.96	31.0	7.46	70	772	752	59
15.03.96	31.5	7.44	20	956	936	87
21.03.96	32.0	7.05	<10	850	840	81
22.03.96	32.0	7.38	<10	857	847	78
25.03.96	32.5	7.30	<10	818	808	-

Table C-50 BOD_5 (mg/L) Measurements for Treatment Plant Unit Operations

Date	Sump	Clarifier	Lagoon I	Lagoon II	Lagoon III
28/02/96	75	0	105	15	-
13/03/96	80	67.5	37.5	2.5	5
20/03/96	77.5	65	55	30	11.5
17/04/96	97.5	-	37.5	22.5	6
22/05/96	80	-	25	25	3
12/06/96	62.5	57.5	22.5	2.5	2.5

Table C-51 Characteristics of Ground Water

Date	Temp (^{0}C)	pH	Alkalinity (mg/L)	Chloride (mg/L)	Hardness (mg/L)
19.03.96	36.0	7.04	210	39.99	194.4
20.03.96	35.0	7.62	189	97.97	243.0
21.03.96	36.0	7.14	168	131.96	286.0
22.03.96	36.0	7.12	241	133.96	267.3
23.03.96	35.0	6.64	178	21.99	167.4
25.03.96	37.0	7.58	210	51.98	205.2
26.03.96	36.0	7.69	168	56.96	210.6

Table C-52 Characteristics of Boiler Feed Water

Date	Temp (^0C)	pH	Alkalinity (mg/L)	Chloride (mg/L)	Hardness (mg/L as $CaCO_3$)
19.03.96	86	8.04	84.0	25.99	32.4
20.03.96	86	8.39	52.5	14.00	10.8
21.03.96	86	7.70	105	65.98	5.4
22.03.96	88	7.93	52.5	25.99	5.4
23.03.96	81	7.12	84	17.99	5.4
25.03.96	86	8.07	84	27.99	16.2
26.03.96	84	8.19	63	17.99	5.4

Table C-53 Characteristics of Drinking Water

Date	Temp (^0C)	pH	Alkalinity (mg/L)	Chloride (mg/L)	Hardness (mg/L as $CaCO_3$)	TS (mg/L)
19.03.96	39.0	7.66	189	61.98	27.0	490
20.03.96	39.0	7.91	189	87.97	37.8	365
21.03.96	39.0	7.51	178	85.98	43.2	340
22.03.96	39.0	7.52	168	101.57	40.5	380
23.03.96	39.0	7.67	168	111.97	21.6	375
25.03.96	39.0	7.91	168	65.98	13.5	375
26.03.96	38.0	8.00	168	51.98	37.8	365

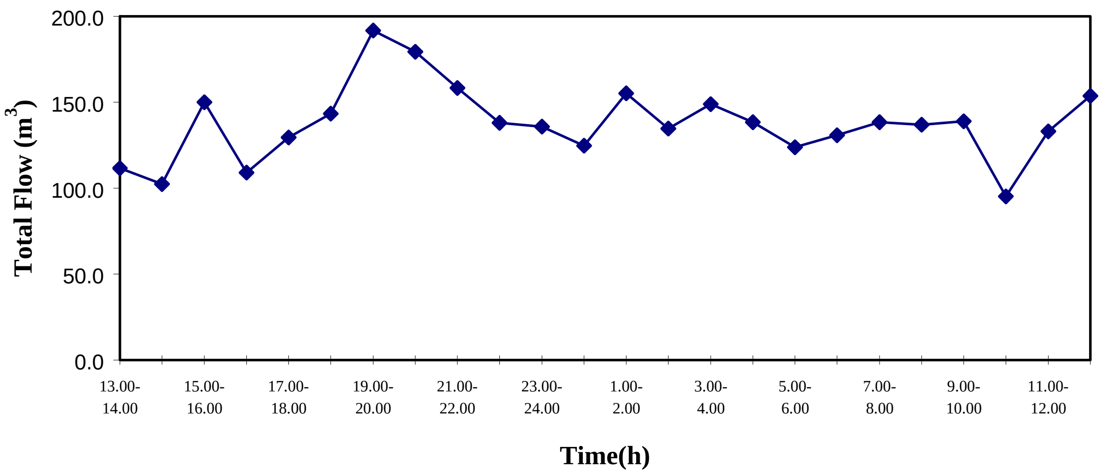


Fig. C-1 The Graph of Time Vs Flow Measured on 04/04/96

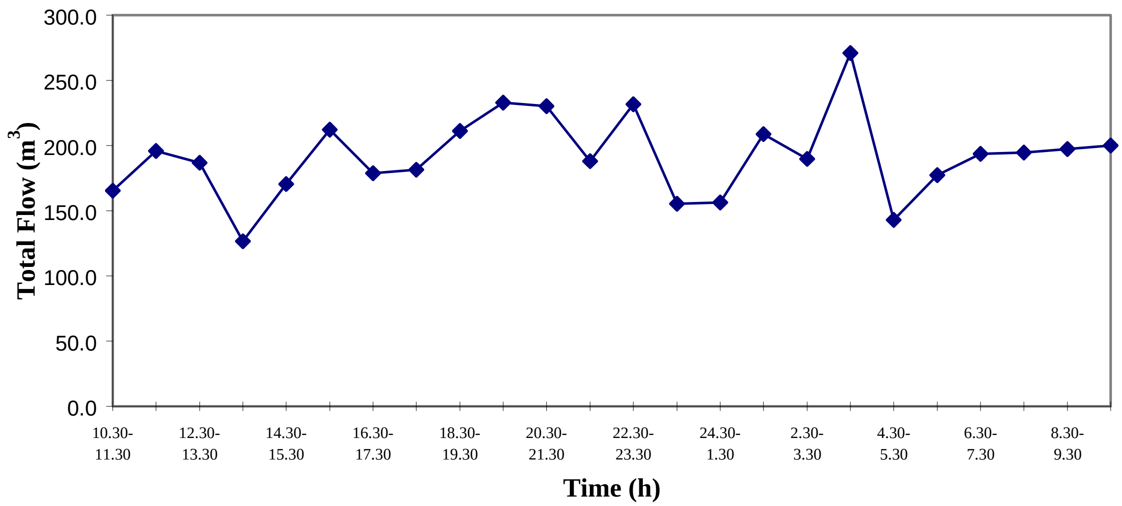


Fig. C-2 The Graph of Time Vs Flow Measured on 10/04/96

Note : 1. The shaded figures in the above tables are not considered in calculating the average.
2. (F) standards for the filtered COD

APPENDIX C
DATA INFORMATION

APPENDIX D
WATER BALANCE INFORMATION

Table D-1 Ground Water Balance for the Three Paper Machines

Description	Quantity (m^3/day)	Description	Quantity (m^3/day)
Total Ground Water Input	2254	Paper Machine I	
		Shower Water	247
		Seal Water	160
		Paper Machine II	
		Shower Water	888
		Seal Water	29
		Paper Machine III	
		Shower Water (Calculated)	846
		Seal Water	84
Total	2254	Total	2254

Note:
1. Duplex Board (PM III) ground water consumption is calculated to 846 m^3/day using the total water consumption of 2254 m^3/day.
2. Printing and Writing Paper (PM II) water consumption was measured as 888 m^3/day as presented in Appendix C, Table C-6. But this include one seal water line which consumes 63 m^3/day of ground water. Therefore the actual quantity of shower water is 824 m^3/day.

Table D-2 Total Water Balance

Inputs	Quantity (m^3/day)
Ground Water	2890
Reuse Water	1121
Total	4011

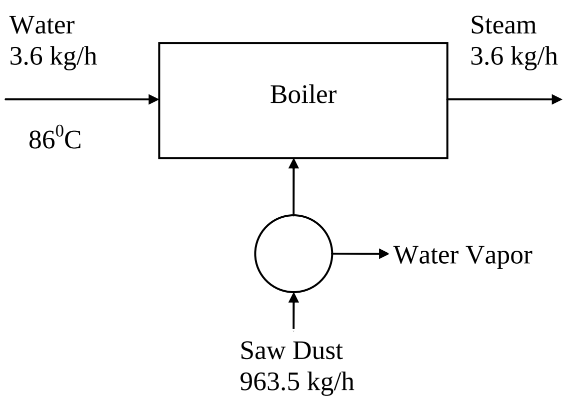
Outputs	Quantity (m^3/day)
Ground water for three paper machines	2254
Reuse water for PM I	982
Reuse water for PM II	139
SP I	70
SP II	202
SP III	87
Softener	24
Staff Housing	100
Human Consumption : Sanitary	4.5
Plant	18
Total	3880.5

APPENDIX E
BOILER EFFICIENCY ANALYSIS

Boiler Efficiency Calculation

Available Data :

Feed water flow rate = 86 m^3/day
Boiler pressure = 7 bar (Saturated steam)
Feed water temperature = 86^0C
Saw dust consumption = 70.9 m^3/day
Saw dust density = 326 kg/m^3
Moisture content of saw dust = 21%
Saw dust heating value = 15 MJ/kg



Heat absorbed by water	= 8,633,088 kJ/h
Dry saw dust	= 761.1 kg/h
Water in saw dust	= 202.3 kg/h
Heat liberated from saw dust	= 11,416,950 kJ/h
Heat required to vaporize saw dust	= 59,482 kJ/h

Therefore net heat supplied to the boiler = 11,416,950 - 59,482 kJ/h
= 11,357,468 kJ/h

Boiler efficiency $= \frac{\text{Heat absorbed by water}}{\text{Heat supplied to boiler}}$
= 76%

APPENDIX F
ECONOMIC ANALYSIS

Table F-1 Cost Analysis for Wastewater Treatment

Month (1996)	Electricity (kWh)	Alum (kg)	Labor ($)	Maintenance ($)	Wastewater (m^3)
January	26,284	22,133	885.32	-	120,415
February	25,075	20,254	827.92	206.24	107,458
March	28,627	16,377	858.56	184.92	130,519
April	25,947	35,966	856.32	182.68	105,454
Average	26,483	23,683	857.04	143.48	115,962

Operating cost proportional to amount of wastewater

Average monthly electricity cost @ 0.0625 $/kWh = 1,652.56 $
Average monthly alum cost @ 0.18 $/kWh = 4,262.96 $
Total carried forward = 5,915.52 $
=======

Treatment cost per cubic meter of wastewater = 0.051 $/$m^3$

Operation cost independent of amount of wastewater

Average monthly labor cost = 857.04 $
Average monthly maintenance cost = 143.48 $
Cost brought forward = 5,915.52 $
Total cost = 6916.04 $
=======

Total cost of wastewater treatment = 0.060 $/$m^3$

Table F-2 Economic Analysis for Cavity Air Floatation

Investment	$	Saving	$/year
Cavity air flotation unit	64,145.56	Ground Water (720X0.105X358)	26,313.00
Micro filter (3 Nos.)	600.00	Reduction in Treatment Cost	12,780.60
3 HP Pumps (3 Nos.)	1,800.00	(720X0.051X358)	
Total	70,545.56	Total	39,093.60
Operating Cost	$/year	Net Saving	
		39,093.60 -16,918.80	22,174.80
Electricity	5,005.92		
Polymer	5,258.32	Pay back	3.18 years
Depreciation	6,654.56	NPV	42,258.16
		IRR	28.96%
Total	16,918.80		

Notes for Tables F-1 and F-2 :

I. Life time of the equipment is 10 years
II. No salvage value for the equipment
III. Current interest rate of 13.75% is constant for each period
IV. Straight line depreciation policy
V. Annual working days for the factory is 358 days.
VI. $NPV = -CF_0 + \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t}$
VII. $IRR = i, CF_0 = \sum_{t=1}^{n} \frac{CF_t}{(1+i)^t}$

t = Life time of the equipment
CF_0 = Investment
CF_t = Annual saving
r = Interest rate

Table F3 Economic Analysis for Reuse Water Treatment Plant

Investment	$	Saving	$/year
Improve Primary Treatment		Ground Water (2500X0.105X358)	93,975.00
		Cost of electricity to pump ground water	429.60
Install self cleaning continuous bar screen at 30mm spacing	8,000.00	2.40 $/day. Assume 50% saving	
		Total	95,604.60
Improve Secondary Treatment		Net Saving	
Chemical preparation system		95,604.60 - 28,206.76	67,397.84
Equipment	7,720.00		
Installation	1,200.00		
Mixing system			
Injection pump and piping	3,000.00		
Installation	800.00		
Operate Reuse Water Treatment Plant			
Reconstruction of sump after clarifier			
Construction cost	1,200.00		
Civil cost	2,800.00		
Construction of sump after Lagoon III			
Civil cost and 2Nos of 20 HP pumps	3,800.00		
Reuse Water Treatment Unit			
Sand filter, Carbon filter, Pressure vessel	78,664.00		
Installation	10,000.00		
Total	117,184.00		
Operating Cost	$/year	Pay back	1.74 years
		NPV	237,908.00
Electricity	8,142.36	IRR	56.88%
Chemical for Chlorinating	9,666.00		
Depreciation	10,398.40		
Total	28,206.76		

APPENDIX G
DESIGN SPECIFICATIONS

Design Calculations for the Reuse Water Treatment Plant

Design of Granular Filter

Design criteria (METCALF and EDDY, 1991)

Media = Sand
Effective size = 0.65 mm
Uniformity co-efficient = 1.5
Filtration rate = 122 L/m^2.min
Depth = 0.6 m
Back wash water = 1.8 m^3/m^2.min
Back wash velocity = 2m/min

Calculated required area = 14.9 m^2
Required diameter = 4.35 m
Selected diameter = 4.5 m
Assume free board of 50% for back washing operation
Required height = 1.2 m

Expected quantity of back wash water = 140 m^3/day

Design of Granular Activated Carbon (GAC) Filter

Design criteria (METCALF and EDDY, 1991)

Contact time for COD removal of 10-20 mg/L = 15-20 min
Hydraulic loading rate = 285 L/m^2.min
Carbon depth = 6 m
Operation pressure = 136 kPa

Calculated area = 6.1 m^2
Required diameter = 2.8 m
Selected diameter = 3 m
Assume 25% free board for back wash.
Required height of the filter = 7.5 m
Designed contact time = 24 min